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COMPUTERS

Their Operation
And Applications

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by

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PREFACE

The purpose of this book is to present basic information about computers, particularly automatic computers – information that has become available mainly in the years since the appearance of this book's predecessor, "Giant Brains or Machines that Think." These years have been very active. They have seen an extraordinary increase in the speed, capacity, and effectiveness of automatic computers – mechanical brains – whatever you wish to call them.

The subject is no longer so new and strange as it was in 1949; more people know more about it, and are familiar with many of the terms employed. Nevertheless, in the glossary we have tried to list and define every expression that has a special meaning in the field of computing machinery. Information or explanation that is in "Giant Brains" has not been repeated to any great extent in this book, which is in many ways a sequel to that one.

This book selects certain topics in the field of machinery that handles information; it discusses these topics; and it omits discussion of many other topics. Such a procedure is not aesthetically satisfying: both writers and readers prefer a more complete and integrated book. But the field of automatic computing machinery is new, vast, and hardly well known by anybody. It seems almost impossible for any two persons even in several years to become authorities in all of the digital computer field, all of the analog computer field, all of the data-processing machinery field, and all of the field of automatic control devices, not to mention other related fields rapidly developing. So there is a choice: either investigate for years to try to find out all the information – a hopeless task – and finally write a book; or else do the best one can to report information already learned – incomplete as it is – indicating areas where other information is needed. We have chosen the second alternative.

Development in the field is so rapid that some of the information in this book will shortly become out of date – the sections describing machines that at time of writing were in the top rank of effectiveness. But many of the concepts, and much of the discussion of applications, of computing machinery in various fields, are, we hope, likely to stay current for some years.

Section III of the book dealing with analog machines, and Section VII:5 dealing with military applications of computers, are the work of Wainwright; the rest of the book is the work of Berkeley.

No authors can ever be completely right. We shall be grateful for any comments, corrections, or criticisms that any reader may be kind enough to send us.

New York 11, N.Y. — *Edmund Callis Berkeley*
Encinitas, Calif. — *Lawrence Wainwright*

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For help in providing communication and a forum for people interested in automatic computing machinery, we would like to express our warm appreciation to the following organizations, whose meetings and publications have been of great benefit to us: the Association for Computing Machinery; the Joint Computer Conference; the Institute of Radio Engineers' Professional Group on Electronic Computers.

The glossary contained in this book is reprinted from "Computers and Automation," vol. 5, no. 1, January, 1956. That glossary in turn has drawn to a considerable extent on previously published glossaries: "Standards on Electronic Computers; Definitions of Terms, 1950" in "Proceedings of the IRE," vol. 39, no. 5, March, 1951; "Glossary" in "Computers and Automation," vol. 2, nos. 2, 4, 9, March, May, Dec., 1953, and vol. 3, no.10, Dec., 1954; "Glossaries – Discussion," in "Computers and Automation," vol. 3, nos. 2 and 3, February and March, 1954; "A Glossary of Computer Terminology" by Grace M. Hopper in "Computers and Automation," vol. 3, no. 5, May, 1954; and "First Glossary of Programming Terminology," Report to the Association for Computing Machinery, June 1954. We express our thanks to the authors and contributors to all these glossaries.

The statements and opinions expressed in this book are our own and do not necessarily represent the views of any organizations with which either one of us may be or has been associated.

Edmund Callis Berkeley

Lawrence Wainwright

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SECTION I

MACHINES THAT HANDLE INFORMATION

I:1 COMPUTERS

It seems clear that the twentieth century will be remembered in the years to come as the century which saw two developments of the first magnitude in human affairs. One of these was the capture of atomic energy, typified by the atom bomb dropped at Hiroshima, Japan, in August 1945. The second of these developments was the harnessing of machinery to handle information in reasonable ways, which has quite appropriately been called the Second Industrial Revolution. This revolution is a parallel of the First Industrial Revolution that began in the late 1700's in England, and that harnessed energy from steam and coal; and like the first, it has many varied aspects: automatic control over processes; automatic handling of materials; robots (machines with sensing, acting, and "thinking" apparatus); automatic processing of data; automatic computing machinery; etc. The part of the Second Industrial Revolution expressed by the words "automatic computing machinery" is the central subject of this book.

What is a Computer?

In investigating and reporting on the subject of automatic computing machinery and its applications and implications, most of what we shall need to do, here and later, all through the investigation, is pose questions and put down answers. And the first of these questions is "What is a computer?".

A *computer* is a person or machine that is able to take in information (problems and data), perform reasonable operations on the information, and put out answers. A computer is identified by the fact that it (or he) handles information reasonably.

For example, a human being aided by pencil and paper may be a computer. He may take in information, write some of it on the paper, perform reasonable operations upon the information and come out with an answer.

Likewise a machine may be able to take in information, record it in the arranging or positioning of some of the equipment inside the machine, perform reasonable operations upon that information and come out with an answer. Both are computers.

Examples of simple mechanical computers which occur in common everyday surroundings in stores, and businesses, and laboratories are:

- an adding machine, which adds numbers and prints on tape;
- a desk calculating machine, which adds, subtracts, multiplies, and divides numbers rapidly, but does not record them;
- a dial telephone system, which is, however, a special purpose, not general purpose, computer; and
- the abacus, a device used in many countries containing rows of beads in a frame conveniently arranged for rapid calculating.

What are Reasonable Operations?

The definition put down above, saying what a computer is, relies on the meaning of two more terms, which need to be clarified: *reasonable operations;* and *information.*

Reasonable operations are logical and mathematical operations. Mathematical operations include addition, subtraction, multiplication, division, taking square root, etc., and also more advanced mathematical operations such as raising to a power, finding the derivative, and integrating. Logical operations include comparing, selecting, sorting, matching, merging, determining the next instruction which is to be performed, etc. These are reasonable operations on information.

Reasonable operations are those operations which are correct logically or mathematically, and the definition of this brand of correctness can be accomplished by tables of accepted results. For example, correct multiplication can be defined in terms of the multiplication table and a few rules.

From the viewpoint of the fundamentals of logic and mathematics, reasonable operations on information have these properties:

- they do not question the objective meaning of the starting data;
- they do not question the factual truth of the starting statements; but
- they do find out the implications contained in these data and statements.

Consider the argument:

"The moon is made of green cheese; anything made of green cheese is a weighty object; and therefore the moon is a weighty object."

Here the argument is logically valid (or computable), and the conclusion is (for other reasons) factually true, although the first premise is false. A computer specializes in deriving conclusions (logical or mathematical) without regard to the objective truth of the starting data.

The fact that reasonable operations do not depend on the meaning of the information is what makes calculation fast. For instance, to add 111 and 444 and obtain 555 for the answer neither the person nor the machine has to remember, or in some way "conceive of," the meaning of these numbers. In an appropriate kind of language, the operations can be carried on with the marks or symbols only. And then, to the everlasting wonder of nearly everybody, if the premises correspond with the real world, so do the conclusions.

What is Information?

The second term we need to clarify is *information*. In the discussion of computers, the word information has a rather special definition: Information is a set of marks that have meaning. Physically, the set of marks is a set of physical objects or a set of arrangements of some physical equipment. Then, out of this set, a selection is made in order to communicate, to convey meaning. For meaning to exist, there has to be a society of at least two persons or machines, a society that requires communication, that desires to convey meaning. By convention, the society establishes the meaning of the marks. The meaning exists independently of the particular kinds of marks that may be used; for example, "it is raining, il pleut, es regnet" all have the same meaning, although English, French, and German are the three kinds of sets of marks in which the meaning has been expressed.

The kinds of physical objects which can be used to express information are extremely varied. Many different kinds of equipment inside a machine may be used to record and manipulate information. In a desk calculating machine, information may be stored and manipulated in small counter wheels bearing geared teeth, and usually having ten positions corresponding to the digits 0, 1, 2 up to 9. In an automobile, a flexible cable running from a gear connected with the drive shaft to an indicator dial in the dashboard, records, by the amount and speed of its turning, the distance traveled by the automobile and its speed. In a great automatic electronic computer, such as the machine known as Univac, information may be recorded and manipulated as sequences of minute electrical pulses which are about a millionth of a second apart; and the presence or the absence of a pulse in a position where either may occur is the basic code which represents information.

For the purposes of computing machines, information is an arrangement or positioning of equipment, and the social meaning of the arrangement, except at the input and the output, makes no difference.

How Can a Machine Take In and Store Information?

A machine can take in, record, and remember information because in every case it contains equipment which can receive and record information. The actual mechanical means, however, may vary widely.

One way of putting information into a machine is by punching holes in paper tape or in a card, and then passing this tape or card into the machine; the presence or the absence of a hole is detected by the machine by means of metal fingers or by closed or opened electrical circuits, and this causes it to store the pattern of the information in some part of its equipment. This is the *digital* form of information, a series of separate and distinct symbols, digits, letters, characters, yeses and noes; and the kind of computer which takes in and manipulates information in this form is called *digital.*

In general, in a digital machine, in the course of a problem, each separate piece of information has to be remembered for a long or short time. It is stored in unchanging form in some of the equipment of the machine, called a *register* or a *location.* This might be, for example, a set of counter wheels, as in a desk adding machine, or a set of relays, as in a telephone system. Many automatic digital computers have 1000 registers for storing internally 1000 pieces of information at any one time. Any piece of information when called for is accessible to the calculating section of the machine with a very small waiting time.

A second way of putting information into a machine is, for example, by turning a dial or a wheel a certain amount, and causing some of the equipment in the machine to record how much turning has taken place. This is the method used in the automobile speedometer and the steering mechanisms of a ship. This is the *analog* form of information, a magnitude of something or other, more exactly, a magnitude of a physical variable such as position, rotation, or voltage. The kind of machine which takes in and manipulates information in this form is called *analog*.

In general, in an analog machine, in the course of a problem, each different quantity occurring (either input or output or intermediate) is remembered for the whole time in a separate mechanism. This might be a rotating shaft, as in a fire control computer, or some electrical component, as in an electronic analog computer. This mechanism by its position or voltage or motion, etc., represents—in fact measures—the quantity in the problem. Some automatic analog computers of very high capacity may have 100 mechanisms for storing internally 100 quantities throughout the problem. Each mechanism is interconnected physically in a way that mirrors the mathematical relationship so that as time goes by, the simultaneous change of all the mechanisms solves the problem.

It should be possible for one and the same machine to take in digital information in some ways and analog information in other ways, and this kind of machine may in the future combine the best features of both types of machines.

A simple everyday example of a small machine that can receive and record information in a digital way is the ordinary date stamp, that can stamp JUN 30, 1954, for instance. The date stamp is made up of a frame, four rollers, and four little rubber belts; one of the belts contains in raised, reversed letters the month symbols JAN, FEB, MAR and so on down to DEC: two more little belts contain each the digits 0, 1, 2, up to 9; and the fourth belt contains say the years 1954, 1955, 1956, 1957, 1958, 1959. The date stamp at the beginning of a day is set by hand so that it records and thereby stores the date which that day is. Then the user of the date stamp, without himself remembering the date, can impress it on any sheet of paper and the machine will immediately state the date. On the following day, the date shown by the stamp can be advanced, of course, by turning small burred wheels next to each roller, thus changing the position of one or more rubber belts. In fact, if we should so desire, we could connect the date stamp to an electric alarm clock set to go off each midnight, thereby providing an impulse which (with a sufficiently Rube Goldberg apparatus) could cause the date stamp to be changed automatically from one date to the next date. We would then have a rudimentary automatic computer, able not only to take in and record information but also to manipulate it logically.

A simple everyday example of a small machine that can receive and record information in an analog way is a thermometer. This machine takes in and records the temperature of its surroundings. The length of its column of bright red liquid, when appropriately *scaled*, matches up with the temperature of the surrounding air. Yet it does not report immediately because it takes about three minutes, when moved into a new environment, for the thermometer to reach the temperature of its environment. One might argue that the graduations on the scale of the thermometer convert it into a digital machine; but this digital reporting (found in all analog computers to make it easy to copy down the answer) is extraneous to the analog character of the machine.

But there is no very easy way to hitch mechanically the temperature-responding length of a column of such liquid; and so analog computers use other means than these for nearly all purposes of computation.

How Does a Machine Actually Compute?

How does a machine succeed in manipulating information reasonably? How does it actually compute?

To explain the different ways in which a computer actually computes, suppose we take a sample operation with information and show how it is handled by a human being engaged in computing and by a machine engaged in computing.

For the sample operation, let us take the operation of finding twice a number. This is the operation expressed by the formula "p equals 2 times n", where p and n are numbers.

A human being will find twice a number in the following way. First, you have to tell him the number. Suppose that it is 76—that is, in this case n is to be 76. Then he will refer to the "two times" multiplication table which he has learned by heart, and will go through a procedure which he also learned by heart while in grade school. On paper he will write:

$$\begin{array}{r} 76 \\ \times 2 \\ \hline 152 \end{array}$$

but under his breath as he writes this, he will say the procedure that he learnt by heart in grade school:

> "2 times 6 is 12; put down the 2 and carry the 1; 2 times 7 is 14, and 1 to carry is 15, put down the 5 and carry the 1; there is nothing in the third column; 2 times zero is zero, and the 1 to be carried makes 1; put down the 1; the answer is 152."

An automatic analog computing machine will find twice a number in the following way. Suppose that the machine represents and stores each number by the amount of turning of a shaft or rod or axle. Imagine two shafts parallel to each other. We slide onto one of the shafts, the one which represents *n*, a gear with say 36 teeth. We slide onto the other shaft, the one which represents *p*, a gear with 18 teeth – half as many teeth. We mesh the gears with each other and tighten them on their shafts so that they will not slip. We put a crank on shaft *n* so that we can turn it and thereby drive shaft *p*. Now we can see that no matter how much or how little we turn shaft *n*, shaft *p* will have to turn twice as much; and if shaft *n* has had 76 turns from its initial or starting position, then shaft *p* without any doubt at all must have had 152 turns from its initial or starting position. We notice that in this case the machine is set to compute twice a number without our having to tell the machine specifically some particular number to begin with.

An automatic digital computing machine will find twice a number in the following way. In the first place such a computer is organized like a railroad system. This railroad system has four main stations; Input; Output; Storage, which may contain 1000 sidings or registers; and Calculator, which may have registers A and B for two numbers being operated on, a register Op for the operation, and a final register R where the result of the operation is delivered. It also has a signal tower, Control. The units of information are like freight cars, which are flashed from one siding to another anywhere in the system, according to the instructions from the tower.

To find twice a number in this kind of computer, here is one typical method. The tower signals the register holding the number *n*, which flashes it into the calculator register A. The tower then flashes 2 into register B, and flashes "Multiply" into register Op. The Calculator then, by means of special circuits which are equivalent to a built-in digital multiplication table, doubles the number. The tower also signals the Calculator what siding in Storage to send the result to. This is done, and the operation is thus finished.

What is an Automatic Computer?

We are now ready to make clear what is an *automatic computer*. It is a computing machine that is able to operate by itself. It has an electric motor or some other source of energy. It has a program (or set of instructions) such that it is able to perform a long sequence of reasonable operations on information, with no human assistance. A modern automatic digital computer is even able to determine a large part of its own instructions by computing them too, and sending them into the Control tower.

The automatic program may, of course, be expressed in any one of many ways: in the wiring together of certain patch cords into certain sockets in terminal boards; in the punched holes of paper tape; in magnetized spots on magnetic tape; or in any of the forms of physical language acceptable to machines. For, any computing machine requires a language that it can deal with easily, just like a human being.

But there is really only one great simple secret – although many people know it by now: a machine is perfectly well able to follow out a long series of instructions, performing reasonable operations, and adjusting them according to circumstances.

The application of this secret is destined to transform the world as we know it.

I:2 TYPES OF AUTOMATIC COMPUTERS

In 1947 it was possible to count the types of automatic computers on the fingers of two hands. In 1955, the types of automatic computers numbered over 170 (see the list at the end of this chapter). In the short space of eight years, this is rather an extraordinary development. Why did this happen?

The floodtide of automatic computers is a consequence of the extraordinary interest and support given to the field of automatic computing machinery by scientists, business, the military, and government. To construct an automatic computer is not easy. A considerable amount of engineering effort, and a considerable quantity of materials and labor are needed to build an automatic computer that will do useful work. In fact, it may be estimated that resources of well over a hundred million dollars, and perhaps over half a billion dollars, were spent in the ten years ending 1955, for the construction of automatic computing equipment.

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The basic reason for this immense investment of resources was that many people began to look at information with new vision. Why rely on "armchair" judgments if you could determine the answer by computation? Why rely on the estimates of "experienced men" if you could replace the estimate with something accurately calculated? Why give up on the problem of shooting down a swiftly moving attacking plane if you could aim your defending guns automatically? In fact, in how many places all through society was "finished" information wanted, and how could it be obtained fairly easily by swift automatic processing of "raw" information?

What Are the Main Classifications of Automatic Computers?

For most purposes, automatic computers are quickly classified according to the following main features: purpose, nature, size, and quantity.

(1) *Purpose.* An automatic computer may, of course, have many purposes. However, the broad classification of automatic computers with respect to this feature is *general purpose,* adapted to solve any problem of rather a large class of problems, or *special purpose,* adapted to solve only problems of a small group of problems.

(2) *Nature.* The classification of automatic computers according to their nature has two aspects:

- (a) the form in which information is handled—either *digital,* in the form of letters or digits, or *analog,* in the form of measurements of physical variables;
- (b) the form in which the information is expressed—*electronic,* operating with information expressed as rapid pulses in electronic tubes(like a television set); *relay,* operating with information expressed mainly in the energizing or non-energizing of relays (like the telephone system); or *mechanical,* operating with information expressed mainly in the positioning of mechanical devices, such as the counter wheels in an ordinary desk calculating machine, or pneumatic devices, or other types of devices.

(3) *Size.* Size is often measured in terms of cost and not in terms

of space occupied, although there is some correlation. A convenient current classification is the following: a *large* computer costs in the neighborhood of $400,000 up; a *medium size* computer costs in the neighborhood of $100,000 to $400,000; and a *small size* computer costs less than $100,000 approximately. These costs will doubtless be lowered in the future.

(4) *Quantity.* Quantity in existence is the main criterion quickly distinguishing between one-of-a-kind computers characteristic of construction in a university laboratory, and many-of-a-kind computers characteristic of construction under production conditions in a factory. The quantity of a type of automatic computer is conveniently classified for present purposes as follows: *zero,* unfinished or dismantled; *one; two; small quantity,* from 2 to 6; *medium quantity,* from 7 to 29; *large quantity,* 30 up.

Future Trends

What are the probable future trends of these features in automatic computers?

Both general purpose computers and special purposes computers will continue to exist and come into existence. It is likely, however, that an interchangeable or universal "machine language" will be developed, so that more and more any piece of information-handling equipment will be able to communicate with any other piece. In this way an installation of computing equipment will become much more flexible than at present. The machine language which is likely to become common and widespread may very well be five-hole punched paper tape, because of its wide use already in telegraph and teletype communication. This will make special purpose computers more useful and less restricted.

Relatively more special purpose computers may actually develop in the future, for several reasons, one of the most important being the tremendous variety of problems involving computing. Some problems have a great deal of input, and others very little input; or a great deal of output, or very little output; and there may be many kinds of combinations. Different types of computing equipment will tend to evolve accordingly. Other factors such as the amount of storage, the amount of calculating capacity, and the amount of programming capacity will influence the future development of special purpose computers.

It is likely that the distinction between analog and digital computers will to some extent disappear. One and the same general purpose computer or computing installation will be able to operate in either fashion, programmed to choose according to convenience in the problems to be solved. Another effect of wider intercommunication among computers will be that good results obtained in one computing system will be quite readily available, by punched tape for example, for use in another computing system.

Automatic digital computers of the future will probably be largely electronic; few will be manufactured without liberal use of electronic principles and components. Large relay and mechanical automatic digital computers are likely to become unimportant. The main reason for this development is the very high speed and demonstrated reliability of electronic automatic digital computers. In addition many new and very efficient computer components are essentially electronic.

Physically, the size of future automatic computers will be smaller. In fact, it is hard to see any limit to the reduction of size of automatic computers because the marks or equipment that represent information inside the computer can be made extremely small. Large size, of course, with resulting large power requirements, is no advantage in itself. One of the best computers of all, the human brain, is remarkably small and efficient. Almost certainly, the most elephantine of general purpose computers located in a single place has already been constructed; a competitor for this distinction may be Harvard Mark II at Dahlgren, Va., which is about 30 feet wide by 40 feet long. And of course any automatic dial telephone system will inevitably remain stretched out over the country.

Future cost will undoubtedly be less. Plenty of competition is at work in the field of producing and selling automatic computers. Already, the heavy initial cost of research and development has been largely paid through government contracts. Many university laboratories make a good deal of their information free to inquirers, since their research and development were supported by the government. In addition, mass production of components of use in computers is under way, particularly in such items as electronic tubes, magnetic tape, diodes (components which allow electric current to flow only in one way), etc.

Restraints on costs because of patents in the computer field appear not likely to be serious, for several reasons. First, many important discoveries are old, such as the use of a magnetic surface for recording information; or they are in the public domain, because of government financing of the work. In addition, a computer is an assembly and interconnection of components; and if one kind of connection is barred by someone else's patent, another kind of connection can very likely be found.

It is a question whether the cost of an automatic computer will go so low that it will be less than the cost of materials to a university laboratory. But this has happened for desk calculators, which no university laboratory dreams of constructing; and it may happen yet for an automatic computer.

The future trend in regard to quantity of a type of a computer is clear. Many of the types of automatic computers built by university laboratories are one-of-a-kind; they will not be repeated; eventually they will be dismantled or given away, because better methods of construction of automatic computers will be available. Also competition will eliminate some types of computers—those that prove to be less efficient or less powerful. The quantity of computer of such a type will remain small or go to zero.

The quantity of the more efficient and useful types of automatic computers will increase greatly. The problem of service, for example, of keeping an automatic computer running efficiently, will give an advantage to the types of automatic computers built by large organizations in a position to maintain a national service organization. The quantity of computer of such a type will increase to a larger and larger figure.

How Many Types of Automatic Computers are There?

A count of the number of types of automatic computers as of 1955 shows at least 170 of them. These types are listed in the inventory given at the end of this chapter. These are the types of automatic computers for which some specific information has been obtained.

A number of types of automatic computers are, however, not included in this table. Many military automatic computers, both general purpose and special purpose, are under various degrees of security classification, and therefore are missing from this list. Also missing are some automatic computers in countries outside of the United States, particularly those in countries of Eastern Europe and Northern Asia.

Another important group of special purpose automatic computers not included in the list are flight simulators, used to train aircraft crews in flying techniques, although the flight simulator never leaves the ground. Another omitted group of automatic equipment for handling information is apparatus that converts automatically from digital to analog form and vice versa. And, finally, the automatic dial telephone system, including dial telephoning at long distance, which is literally a very extensive computer, has not been listed specifically.

The following listing reports all automatic computers in existence currently known to the authors. Each entry when complete gives: the name of the computer (and the interpretation of abbreviating letters) / the maker of the computer, and the place where made; and if the quantity of the computer produced is 1 or 2, the place where each computer is located / the purpose of the computer, whether special purpose or general purpose; the nature of the computer; the approximate size or capacity of the computer; and the approximate quantity of the computer in existence. Some words like "Model" and "Type" have been omitted from the names of computers; usually the initial letters of the company name have been substituted.

If only the name of the computer has been learned, a reference where the computer is mentioned or described is given.

In most cases the maker of the computer is the key to more information about the computer. The maker's address in most cases appears in the "Roster of Organizations Making Computing Machinery" (see p. 000).

The key to the special abbreviations follows:

Purpose (p)

Gp	General purpose
Sp	Special purpose

Nature of Computer (c)

Dc	Digital computer
Ac	Analog computer
Ec	Electronic computer
Rc	Relay computer
Mc	Mechanical computer

Size (s)

Ss	Small size or low capacity
Ms	Medium size or medium capacity
Ls	Large size or large capacity

Quantity (q)

0q	Zero (i.e., unfinished or dismantled)
1q	One
2q	Two
Sq	Small quantity, about 2 to 6
Mq	Medium quantity, about 7 to 30
Lq	Large quantity, over 30
?q	Unknown quantity

Some other abbreviations have been used which can be easily guessed, like those in a telephone book.

LIST OF AUTOMATIC COMPUTERS

ABC (Automatic Binary Computer) / Air Force Cambridge Research Center, Cambridge, Mass.; located there / Gp EDc Ms 1q

Abel — same as the ONR Relay Computer, which see

Ace (Automatic Computing Engine — pilot model) / National Physical Laboratory, Teddington, England; located there / Gp EDc Ms 1q

Ace (Automatic Computing Engine — engineered model) / English Electric Co., Stafford, Eng / Gp EDc Ms ?q

Aeracom (Bureau of Aeronautics Analog Computer) / Aerial Measurements Laboratory, Northwestern Univ, Evanston, Ill; located there / Gp EAc Ls 1q

Alwac / Logistics Research Inc, Redondo Beach, Calif / Gp EDc Ms Sq

Amos (Automatic computer Ministry of Supply) — a Ferranti computer; see Ferranti

Anacom (Analog Computer) / Westinghouse Electric Co, Pittsburgh; located there / Gp EAc Ls 1q

Analog Computer / Electronic Associates, Long Branch, N J / Gp EAc Ls ?q

Anser (Analog Simulator and Computer) 300-A / Davies Laboratories, Inc, Riverdale, Md / Sp EAc ?s 0q

Aperc (All Purpose Electronic (Rayon) Computer) Birkbeck College, London, Eng; located at British Rayon Research, Manchester, Eng / Gp EDc Ms 1q

Apex (All Purpose Electronic X-ray Computer) / Birkbeck College, Univ of London, England; located there / Gp EDc Ms 1q

Arc (Automatic Relay Computer) / Birkbeck College, Univ of London, London, England; located there / Gp RDc Ms 1q

Arra (Automatische Relais Rekenmachine Amsterdam) / Mathematisch Centrum, Amsterdam, the Netherlands; located there / Gp EDc (not relay) Ls 1q

ASCC (Automatic Sequence Controlled Calculator) — SEE: IBM Harvard Automatic Sequence Controlled Calculator, or Harvard Mark I

Avidac (Argonne Version Institute's Digital Automatic Computer) /Argonne Natl Lab, Chicago; located there / Gp EDc Ls 1q

Barber-Colman-Stibitz Computer /Barber-Colman Co., Rockford, Ill; located there / Gp EDc Ss 1q

Bark (Binary Automatic Relay "K"omputer) / Swedish Board for Computing Machines, Drottninggatan 95A, Stockholm, Sweden; located there / Gp RDc Ls 1q

Beac (Boeing Electronic Analog Computer) / Boeing Airplane Co, Seattle / Gp EAc Ms Mq

Bell Model V / Bell Telephone Labs, New York; located at Ballistic Research Laboratories, Aberdeen Proving Ground, Aberdeen, Md / Gp RDc Ls 2q

Bell Model VI / Bell Telephone Labs, Murray Hill, N J; located there / Gp RDc Ms 1q

Bendix Digital Differential Analyzer D 12 / Bendix Computer Div, Bendix Aviation Corp, Los Angeles, Calif / Sp EDc Ms Sq

Bendix G-15A / Bendix Computer Div, Bendix Aviation Corp, Los Angeles, Calif / Gp EDc Ms Sq

Bendix G-150 / Bendix Computer Div, Bendix Aviation Corp, Los Angeles, Calif / Gp (Digital differential analyzer) EDAc Ms 0q

Besk (Binar Elecktronisk Sekvens-Kalkylator) / Swedish Board for Computing Machines, Drottninggatan 95A, Stockholm, Sweden; located there / Gp EDc Ls 1q

Binac (Binary Automatic Computer) / Eckert-Mauchly Div. Remington-Rand, Phila, Pa; located at Northrop Aircraft, Hawthorne, Calif / Gp EDc Ss 1q

Burroughs E 101 / Burroughs Corp, Phila / Gp EDc Ss Sq

Burroughs Laboratory Computer / Burroughs Adding Machine Co, Phila, Pa; located there / Sp EDc Ls 1-2q

Burroughs Unitized Digital Electronic Computer / Burroughs Corp; located at Wayne Univ, Compn Lab, Detroit / Gp EDc Ls 1q

Cadac — SEE CRC

Caldic (California Digital Computer) / Univ of Calif, Berkeley, Calif; located there / Gp EDc Ms 1q

CEC 30-201 / Consolidated Engrg Co, Pasadena, Calif / Gp EDc Ss Sq

CEC 36-101 (Consolidated Engrg Corp. 36-101) ElectroData Corp, affiliate of Consol Engrg Corp, Pasadena, Calif / Gp EDc Ls Sq

Circle Computer / Hogan Labs, New York, & Nuclear Development Assoc, White Plains, NY / Gp EDc Ss Sq

Computer / Dynamic Analysis and Control Laboratory, Mass Inst of Technology, Cambridge, Mass; located there / Gp EAc Ls lq

Computer / Electronics Div, AERE, Harwell, England; located there / EDc

Computer / Haller, Raymond, and Brown, State College, Pa; located there / Sp EDc Ss lq

Computer / Imperial College, Univ of London, London; located there / Gp RDc ?s lq

Computer / Mathematisch Centrum, Amsterdam, Netherlands; located there / Gp RDc Ls lq

Computer / Naval Special Devices Center, Pt Washington, NY; located there / Gp Dc Ls lq

Computers / Academy NAUK, Leningrad, and other groups, USSR; located Leningrad and ? / Gp EDAc Ls, etc ?q / referred to in "The Soviet Union: Automatic Digital Computer Research" by T Fortuna, "Computers and Automation", Sept, 1953

Computyper / Friden Calculating Machine Co, San Leandro, Calif / Gp MDc Ss ?q

CRC 101 (Comp Res Corp 101) / National Cash Register Co, Electronics Division, Hawthorne, Calif / Sp EDc ?s ?q

CRC 102 (also called Cadac 102; Computer Research Corporation 102) / National Cash Register Co, Electronics Division, Hawthorne, Calif; located at Project Lincoln, Mass Inst of Technology, Bedford Airport, Mass / Gp EDc Ls lq

CRC 102A (also called Cadac 102A; Computer Research Corporation 102A) / National Cash Register Co, Electronic Computer Division, Hawthorne, Calif / Gp EDc Ls Mq

CRC 102D / National Cash Register Co, Electronic Computer Div, Hawthorne, Calif / Gp EDc Ls Sq

CRC 105 (Computer Research Corporation 105) / National Cash Register Co, Electronics Div, Hawthorne, Calif / Sp (decimal digital differential analyzer) EDc Ls Mq

CRC 107 (Computer Research Corporation) / National Cash Register Co, Electronics Div, Hawthorne, Calif / Gp EDc Ls Sq

CSIRO Mark I / Radiophysics Div, Commonwealth Sci and Indus Res Org, Sydney, Australia; located there / Gp RDc Ms lq

Cuba (Calculator Universel Binaire de l'Armement) / Societe d'Electronique et d'Automatisme; Paris, France; located at Laboratoire Central de l'Armement, Paris, France / Gp EDc Ls lq

Davis Computer / USAF Inst of Tech, Wright-Patterson Air Force Base, Dayton, Ohio; located there / Sp EAc Ms lq

Deuce / — / referred to in footnote 7 in "Computing Bit by Bit" by A L Samuel, in "Proc IRE", Oct, 1953, p. 1225

Diad (Drum Informatin Assembler and Dispatcher) / Bell Telephone Labs, Murray Hill, N J; located there / Sp Dc Ls lq

Differential Analyzer No. 1 / MIT Electrical Engrg Dept, Mass Inst of Technology, Cambridge, Mass; located at Wayne Univ Compn Lab, Detroit, Mich / Gp MAc Ls Oq

Differential Analyzer / General Electric Co, Schenectady; located there / Gp MAc Ls lq

Differential Analyzer / Moore School of Electrical Engrg, Univ of Pa, Phila; located there / Gp MAc Ls lq

Differential Analyzer No. 2 / MIT Electrical Engrg Dept, Cambridge, Mass; located there / Gp EAc Ls lq

Dyseac ("di-"-second-Standards Eastern Automatic Computer) / National Bureau of Standards, Washington; mounted on a truck / Gp EDc Ls lq

Ease (Electronic Analog Simulating Equipment) / Berkeley Division, Beckman Instrument Co, Richmond, Calif / Gp EAc ?s ?q

Edsac / Univ Mathematical Lab, Cambridge, England; located there / Gp EDc Ls lq

Edvac (Electronic Discrete Variable Automatic Computer) / Moore School of Electrical Engrg, Univ of Pa, Phila; located at Ballistic Research Labs, Aberdeen Proving Ground, Aberdeen. Md / Gp EDc Ls lq

Elecom 100 / Electronic Computer Division of Underwood Corp, L I City N Y / Gp EDc Ss Sq

Elecom 120 / Electronic Computer Division of Underwood Corp, L I City N Y / Gp EDC Ss Sq

Elecom 200 (also called Ordfiac) / Electronic Computer Division of Underwood Corp, L I City, N Y; located at Letterkenny Ordnance Depot, ? / Gp EDc Ls lq

Elliot 402 / Elliott Brothers, Computing Machine Division, Borehamwood, Herts, Eng / Gp EDc Ls ?q

Elliott-NRDC Computer 401 Mk 1 / Elliott Brothers Res Labs, Borehamwood, Herts, England; located there / Gp EDc Ls lq

Eniac (Electronic numerical integrator and calculator) / Moore School of Electrical Engrg, Univ of Pa, Phila, Pa, and Ballistic Res Lab, Aberdeen, Md; located at Ballistic Research Labs, Aberdeen / Gp EDc Ls lq

ERA 1101, 1102, 1103 / Engineering Res Assoc Div of Remington Rand, St Paul, Minn / Gp EDc Ls Sq

Ferranti / Ferranti Electric Co, Moston, Manchester, England / Gp EDc Ls Mq

Ferut—the Ferranti computer at the University of Toronto; SEE Ferranti

Flac (Florida Automatic Computer) / Air Force Missile Test Center, Patrick AFB, Fla; located there / Gp EDc Ls lq

G 1 (Göttingen) / Max-Planck-Institut für Physik, Gottingen, Germany; located there / Sp EDc Ss lq

G 2 (Göttingen) / Max-Planck-Institut für Physik, Gottingen, Germany / Gp EDc Ls lq

Gamma 3 / Compagnie des Machines Bull, Paris, France / Gp EDc Ms Mq

GEDA (Goodyear Electronic Differential Analyzer) L2, L3, N3 (linear and nonlinear models) / Goodyear Aircraft Corp, Akron, Ohio / Gp EAc ?s ?q

Harvard Mark I—SEE: IBM Automatic Sequence Controlled Calculator

Harvard Mark II / Harvard Compn Lab, Cambridge, Mass; located at Naval Proving Ground, Dahlgren, Va / Gp RDc Ls lq

Harvard Mark III / Harvard Compn Lab, Cambridge, Mass; located at Naval Proving Ground, Dahlgren, Va / Gp EDc Ls lq

Harvard Mark IV / Harvard Compn Lab, Cambridge, Mass; located there / Gp EDc Ls lq

Harwell Computer / Atomic Energy Research Establishment, Harwell, Berkshire, Eng; located there / Sp REDc (dekatrons) Ms lq

HEC (Hollerith Electronic Computers) 1 and 2 / British Tabulating Machines Co, London, Eng / ?p ?c ?s ?q

Hughes Airborne Control Computer / Hughes Res & Dev Labs, Culver City, Calif / GSp EDc Ms ?q

Hurricane Computer — SEE: Raydac

IAS Computer — SEE: Inst for Advanced Study Computer

IBM 602A (Calculating Punch) / International Business Machines Corp., New York / Gp (short sequences) RDc Ss Lq

IBM 604 (Electronic Calculating Punch)/ International Business Machines Corp, New York / Gp (60 program steps) EDc Ss Lq

IBM 607 (Electronic Calculator) / International Business Machines Corp, New York / Gp (140 program steps) EDc Ss Mq

IBM 650 (IBM Magnetic Drum Calculator) / International Business Machines Corp, New York / Gp EDc Ms Sq

IBM 701 (Electronic Data Processing Machine for Scientific Purposes) / International Business Machines Corp, New York / Gp EDc Ls Mq

IBM 702 (Electronic Data Processing Machine for Business Purposes) / International Business Machines Corp, New York / Gp EDc Ls Sq

IBM 703 (Electronic Data Processing Machine for File Maintenance) / International Business Machines Corp, New York / Sp EDc Ls ?q

IBM 704 (Electronic Data Processing Machine for Scientific Purposes) / International Business Machines Corp, New York / Gp EDc Ls ?q

IBM Automatic Sequence Controlled Calculator, or Harvard Mark I / International Business Machines Corp, Endicott, N Y, and Harvard Univ, Cambridge; located at Harvard Compn Lab, Cambridge, Mass / Gp RDc Ls 1q

IBM Card Programmed Calculator / International Business Machines Corp, New York, N Y / Gp EDc Ms Lq

IBM SSEC (Selective Sequence Electronic Calculator) / International Business Machines Corp, New York, N Y / Gp EDc Ls Oq (dismantled)

Icce (Imperial College Computing Engine) / Imperial College of Science and Technology, London, Eng; located there / Gp Rc Ls 1q

IDA Electronic Slide Rule / Computer Corp of America, N Y / Gp EAc ?s ?q

Illiac (Univ of Illinois Automatic Computer) / Univ of Illinois, Urbana, Ill; located there / Gp EDc Ls 1q

Institute for Advanced Study Computer / Inst for Advanced Study, Princeton, N J; located there / Gp EDc Ls 1q

Institut Blaise Pascal Computer / – / referred to in a report by L Couffignal in the “Proceedings of a Second Symposium”, edited by H H Aiken, Harvard University Press, 1951, p 374

IRSIA-FRNS Computer / Bell Telephone Mfg Co, Antwerp, Belgium / Gp EDc Ls 1q

Jaincomp A, B, B1 / Jacobs Instrument Co, Bethesda, Md / Sp EDc Ss Sq

Jaincomp C / Jacobs Instrument Co, Bethesda, Md / Sp EDc Ss 1q

Jaincomp D / Jacobs Instrument Co, Bethesda, Md / Sp EDc Ss Sq

Johnniac – Same as the Rand Computer, which see

Junior Johnniac – SEE Rand Junior Johnniac

Kalin-Burkhart Logical Truth Calculator / T A Kalin & W Burkhart, Cambridge, Mass; located at Monrobot Corp, Morris Plains, N J / Sp Rc Ss 1q

Leo (Lyons Electronic Office) / J Lyons and Co, Ltd, London; located there / Gp EDc (like Edsac) Ls 1q

Logistics Computer / Engineering Res Assoc Div, Remington Rand, St Paul; located at Logistics Research Project, George Washington Univ, Washington, D C / Sp EDc Ls 1q

Lorpgac / – / mentioned in footnote 7 in “Computing Bit by Bit” A L Samuel, in “Proc IRE”, Oct 1953, p 1225

Los Alamos Computer – same as Maniac, which SEE

Mac III 3 / Magnavox Research Labs, Los Angeles, Calif / Gp EDc Ms ?q

Madam / – / referred to in report by F C Williams and others, in “Proc Instn of Elec Engrs”, vol 98 (1951), p 13

Maddida (Magnetic Drum Digital Differential Analyzer) / Bendix Computer Div, Los Angeles, Calif / Gp EDAc Ms Sq

Magic (Magnetic and Germanium Integer Calculator) / Wharf Engrg Laboratories, Fenny Compton, Warwickshire, Eng / ?p EDc ?s ?q

Magnetronic Reservisor / The Teleregister Corp, Stamford, Conn; located at American Airlines, La Guardia Airport, New York / Sp (reservations inventory) EDc Ls 1q

Manchester Computer / “Univ of Manchester, England; located there / Gp EDc Ls 1q

Manchester Electronic Computer – same as Ferranti computer, which SEE

Maniac (Mathematical Analyzer, Numerical Integrator and Computer) / Los Alamos Scientific Laboratory, Los Alamos, New Mexico; located there / Gp EDc Ls 1q

Mark 22 Computer (Bell Telephone Model IV computer) / Bell Telephone Laboratories, New York; located at Naval Research Laboratory, Washington, D C / Sp RDc Ls 1q

Midac (Michigan Digital Automatic Computer) / Willow Run Res Cr, Univ of Michigan, Ypsilanti, Mich; located there / Gp EDc Ls 1q

Midsac / Willow Run Research Cr, Univ of Michigan, Ypsilanti, Mich; located there / Gp EDc Ls 1q

Milac (Miller Analog Computer) / William Miller Instruments, Inc, Pasadena, Calif / Gp EAc Ls Sq

Minac (Minimal Automatic Computer) / Digital Computing Group, California Inst of Technology, Pasadena, Calif / Gp EDc Ss Oq

Miniac / Marchant Research Inc, Oakland, Calif / Gp EDc Ss 2q

Monrobot (V, MU, etc) / Monrobot Corp, Morris Plains, N J / Gp EDc Ls Mq

Mosaic (Ministry of Supply Arithmetical

Integrator and Calculator) / Post Office Research Section, London, Eng; located at Radar Research Establishment, Malvern, Eng / Gp EDc Ls 1q

MSAC (Moore School Automatic Computor) / Moore School of Electrical Engrg, Univ of Pa, Phila, Pa; located there / Gp EDc Ls Oq

Narec (Naval Research Laboratory Computer) / Naval Res Lab, Washington, D C; located there / Gp EDc Ls 1q

NBS Computer – Same as Seac, which SEE

Network Analyzer / Franklin Inst Labs for Research and Development, Phila / Gp EAc Ls 1q

Network Analyzer – AC / General Electric Company, Schenectady; located there / Gp EAc Ls 1q

Network Analyzer – AC / Westinghouse Electric Co, Pittsburgh; located there / Gp EAc Ls 1q

Network Analyzer – DC / General Electric Company, Schenectady; located there / Gp EAc Ls 1q

Network Analyzer – DC / Westinghouse Electric Co, Pittsburgh; located there / Gp EAc Ls 1q

Nicholas (Nickel Delay-Line Storage Computer) / Elliott Brothers Res Labs, Borehamwood, Herts, England; located there / Gp EDc Ss 1q

Norc (Naval Ordnance Research Computer) / International Business Machines, New York; to go to Naval Proving Ground, Dahlgren, Va / Gp EDc Ls 1q

Norwegian Computer / Central Institute, Royal Norwegian Council for Scientific and Industrial Research, Norway; located at Norwegian Computing Centre, Oslo University, Blindern, Norway / Gp EDc Ms 1q

Oarac / General Electric Co, Syracuse, N Y; located at U S Air Force, Aeronautical Research Lab, Wright-Patterson Air Force Base, Dayton, Ohio / Gp EDc Ms 1q

Omibac / Aeronautical and Ordnance Systems Div, General Electric Co, Schenectady, N Y; located there / Gp EDc Ls 1q

ONR Relay Computer (Office of Naval Research) /-; located at Logistics Research Project, George Washington Univ, Washington, D C / Gp RDc Ms 1q

Oracle (Oak Ridge Automatic Computer & Logical Engine) / Argonne Natl Lab, Chicago; located at Oak Ridge Natl Lab, Oak Ridge, Tenn / Gp EDc Ls 1q

Ordfiac – Same as Elecom 200, which SEE

Ordvac / Univ of Illinois, Urbana, Ill; located at Ballistic Research Labs, Aberdeen Proving Ground, Aberdeen, Md / Gp EDc Ls 1q

Perm (Programmgesteuerte Elektronenrechenmaschine, Munchen) / Technische Hochschule, Munich, Germany / Gp EDc Ls 1q

Philbrick Computer / G A Philbrick Res, Inc, Boston / Gp EAc Ms Lq

Ptera (Postal Telecommunications Automatic Calculator) / Central Laboratory of the Postal and Telecommunications Services, the Hague, Netherlands / Gp EDc Ls 1q

R-PAC (Recorder Playback Automatic Computer) / Penn State College, State College, Pa; located there / Sp EAc Ss 1q

R 4 S /Eidgenossische Technische Hochschule, Zurich, Switz; to be located there / Gp EDc Ls Oq

Rand Computer / Rand Corp, Santa Monica, Calif; located there / Gp EDc Ls 1q

Rand Junior Johnniac / Rand Corp, Santa Monica, Calif; located there / Sp EDc Ss 1q

Rascal (Royal Air Force Sequence Controlled Calculator Mark II) / Royal Aircraft Establishment, Farnborough, Hampshire, Eng; located there / Gp EDc Ms 1q

Raydac (Raytheon Digital Computer) / Raytheon Mfg Co, Waltham, Mass; located at Naval Air Missile Test Center, Pt Mugu, Calif / Gp EDc Ls 1q

Reac 200, 300 / Reeves Instrument Co, New York / Gp EAc Ls Ms Lq

Rechenautomat IPM / Institut für Praktische Mathematik, Technische Hochschule, Darmstadt, Germany; located there / Gp EDc Ls 1q

Remington Rand 409-2 and 409-2R / Remington Rand, Inc., New York / Gp REDc Ss Mq

Remington Rand 1101, 1103 – same as ERA 1101, 1103, which SEE

Remington-Rand 409 Computer / Remington Rand, New York / Gp EDc Ss ?q

S-FAC (Structure Factor Analog Computer) / Penn State College, State Pa; located there / Sp EAc Ss 1q

Seac (Standards Eastern Automatic Computer) / National Bureau of Standards, Washington, D C; located there / Gp EDc Ls 1q

Sec (Simple Electronic Computer) / Birkbeck College, Univ of London, England / located there / Sp EDc Ss ?q

Simon / Berkeley Enterprises, Inc, New York, and others / Sp RDc Ss 3q

Simplac (Simple Automatic Electronic Computer) / Berkeley Enterprises, Inc, New York / Gp EDc Ss Oq

Spec (Special Purpose Electronic Computer) or USAF-Fairchild Computer / NEPA Project, Fairchild Engine and Airplane Co, Oak Ridge, Tenn / Sp EDc Ms Oq (dismantled)

Statac (Statistical Automatic Computer) / National Bureau of Standards, Washington, D C; located there / Sp Dc ?s 1q

Stevens Institute of Technology Digital Differential Analyzer / Experimental Towing Tank, Stevens Institute of Technology, Hoboken, N J / Sp EDc Ms 1q

Swac (Standards Western Automatic Computer) / National Bureau of Standards, Los Angeles, Calif; located there / Gp EDc Ls 1q

TAC (Tokyo Automatic Computer) / Tokyo Shibaura Electric Manufacturing Co, Tokyo, Japan; located at the Univ of Tokyo, Tokyo, Japan / Gp EDc Ls 1q

TC-1 / International Telemeter Corp, Los Angeles, Calif / Gp EDc Ls Oq

Tokyo Mark I / Laboratory of Applied Mathematics, Electrotechnical Laboratory, Tokyo, Japan; located there / Sp RDc Ss 1q

Tokyo Mark II / Laboratory of Applied Mathematics, Electrotechnical Laboratory, Tokyo, Japan; located there / Gp RDc Ls 1q

TRE Computer (Telecommunications Research Establishment Computer) / Telecommunications Research Establishment, Great Malvern, England; located there / Gp EDc Ls 1q

Typhoon Computer / Radio Corporation of America, Princeton Laboratories, N J; located ? / Gp EAc Ls 1q

Udec II (Unitized Digital Electronic Computer) / Burroughs Corp, Electronic Instruments Div, Phila, Pa / Gp EDc Ls 1q

Utec (Univ of Toronto Electronic Computer) / McLellan Lab, Univ of Toronto, Toronto, Canada; located there / Sp EDc Ss 1q

Univac / Eckert-Mauchly Div, Remington Rand, Inc, Phila, Pa / Gp EDc Ls Mq

Univac 60 – same as Remington Rand 409, which see

Univac 120 – same as Remington Rand 409-2, which see

Univac Scientific Computer – same as ERA 1103, which see.

Whirlwind I / Digital Computer Lab, Mass Inst of Tech, Cambridge 39, Mass; located there / Sp EDc Ls 1q

Wisc (Wisconsin Integrally Synchronized Computer) / Univ of Wisconsin, Electrical Engrg Dept, Madison, Wisc; located there / Gp EDc Ls 1q

X-RAC (x-ray analog computer) / Penn State College, Pa; located there / Sp EAc Ms 1q

Zuse Model 5 / Konrad G Zuse, Neukirchen, Germany; located at Leitz Optical Works, Wetzlar, Germany / Gp RDc Ss 1q

Zuse Model IV / Konrad G Zuse, Neukirchen, Germany; located at Swiss Federal Inst of Tech, Zurich, Switzerland / Gp RDc Ls 1q

SECTION II

AUTOMATIC DIGITAL COMPUTING MACHINES

II:1 THE AUTOMATIC DIGITAL COMPUTER

Conception and Reality

The idea of an *automatic digital computer,* a machine able to perform great numbers of operations of both arithmetic and logic in a reasonable and useful sequence, is more than 120 years old. But the reality, a physically existing machine able to operate with physical pieces of information, is no older than 1944. That was the year when the first one of the modern automatic digital computers started operating: the Harvard IBM Automatic Sequence Controlled Calculator, also called the Harvard Mark I. This machine was a cooperative development by International Business Machines Corporation and Professor Howard H. Aiken of Harvard; and since August 1944, it has operated at about three operations a second, days, nights, and weekends (with minor interruptions) year after year after year.

Compressed into the few short years since Mark I began to work, many more developments in the computer field have occurred. Two of the main developments have been:

1 – the recording of information in new physical mediums, of which perhaps the most far-reaching consists of polarized spots on a magnetic surface;

2 – calculation using electronic tubes and transistors, obtaining speeds in some cases as high as 100,000 additions a second.

Information

As pointed out previously, all computing equipment handles information, and handles it in reasonable operations; *information* can be defined as a set of marks that have meaning, such as the gradations marking position written on a slide rule, or the numerals marking position written on a counter wheel, or the states of an electronic tube either conducting or not conducting; and *reasonable operations* with information can be defined by tables like the multiplication table and rules like the rules for carrying in addition, and require very little attention to meanings.

In the design of automatic digital computers, the basic unit of information that has developed and received recognition is the *binary digit* or *bit*. There are only two binary digits: 1 and 0. They may correspond to a yes or a no, a check mark (√) or a cross (x), a report about a statement that it is true or false. They may also correspond to an on-condition or an off-condition of a circuit element, an electronic tube conducting or not conducting, a relay energized or not energized, a hole punched or not punched, etc. The word *bit* is a blend of the "bi" for binary and the "it" of digit, and also of course connotes the idea of something small.

Ordinary information is expressed in characters. A *character* is a lower-case letter a to z, or an upper-case (or capital) letter A to Z, or a digit 0 to 9, or a punctuation symbol, or any other single symbol used in writing. The total number of different characters occurring in a written context usually ranges from about 60 to about 100. No single element of hardware so far used in automatic computers can have as many as 60 easily distinguishable states; and so when a character is represented in a computer, combinations of the states of two or more hardware elements are employed.

The combinations of two binary digits 00, 01, 10, 11 will express four characters. The combinations of three binary digits will express eight characters. Four will express 16 characters; five will express 32; six will express 64; and seven will express 128. Consequently, punched paper tape or magnetic tape will ordinarily have five, six, or seven channels, so that each row of combinations of the presence or absence of holes or polarized spots will designate characters, depending on the context.

A decimal digit expressed as such in hardware is rare in most automatic computing equipment; most high-speed digital equipment regularly uses hardware with only two distinct states, instead of hardware with ten states to be kept distinct. However, a decimal digit is still expressed as one of ten positions of a counter wheel, or as one of ten punches in a column of a punch card.

In nearly all digital computers, information is regularly stored and handled in sets of a fixed number of characters, such as 36 binary digits, or 10 decimal digits and algebraic sign (equivalent to one more binary digit), or 12 characters, any one of which is expressed by 6 binary digits. Such a set is called a *machine word,* or simply *word.* A place in the computing equipment where such a word may be stored in appropriate hardware until needed, is called a *register.*

Binary Notation

Arithmetic may be performed using numbers expressed only in binary digits. This is known as arithmetic in *binary notation,* or arithmetic in the *scale of two.* When counting by two's, the first dozen numbers zero to eleven are represented as 0, 1, 10, 11, 100, 101, 110, 111, 1000, 1001, 1010, 1011. The positions of the digits 1 and 0 designate powers of two; thus 1011 means 1 times two cubed or eight, plus 0 times two squared or four, plus 1 times two to the first power or two, plus 1 times two to the zero power or one; this is equal to one eight plus no four's plus one two plus one one, which is eleven. A *binary number* is a number written in binary notation. The *binary point* in a binary number is the point which marks the place between positive powers of two and negative powers of two, and is of course analogous to the decimal point in a decimal number. Thus, 100.101 means four, one half, and one eighth, or four and three eighths.

Binary arithmetic is very simple.* For example, the complete binary addition and multiplication tables are as follows:

+	0	1
0	0	1
1	1	10

×	0	1
0	0	0
1	0	1

It is easier to design high-speed digital computers to perform binary arithmetic than decimal arithmetic; but good circuits using binary elements to perform decimal arithmetic can also be designed and it seems likely that high-speed computers using decimal arithmetic will continue to be common.

Octal Notation

When a binary number contains many digits, like 10,110,111,011, human beings find it troublesome to read. Consequently, hand in hand with binary notation *octal notation* may be employed—notation of numbers in the scale of eight. The binary number is separated into triples and each triple is represented by one of the octal digits 0, 1, 2, 3, 4, 5, 6, 7. The number just mentioned becomes 010,110,

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*For more information about binary arithmetic and how to carry it out, see pages 216 to 219 in "Giant Brains", reference in bibliography.

111,011 and is reported as the *octal number* 2673, or two times eight cubed, plus six times eight squared, plus seven times eight, plus three times one. Octal notation is convenient and often customary, in discussing numbers being operated on by binary machines, because of the ease of reading of the numbers, and yet the conversion from binary notation to octal notation and vice versa is immediate.

Decimal Notation

The most convenient representation of numbers for nearly all purposes is, of course, decimal. Converting a large decimal number into its equivalent in binary notation, and equally, converting a large binary number into its equivalent in decimal notation, are awkward processes. An automatic digital computer, it is true, may be instructed to perform the change automatically; but if the computer is not working properly, and the operators and maintenance men are seeking to discover what numbers are in the machine here and there, the pure binary numbers are very troublesome to deal with. Consequently, a system which is widely used is to translate each decimal digit separately into combinations of four or more binary digits, which are spoken of as *codes* for decimal digits. The result is *coded-decimal notation.*

Common examples of coded decimal notation are:

Decimal Digit	The 8-4-2-1 Scheme	The 7-4-2-1 Scheme	The 5-4-2-1 Scheme	The Excess-Three Scheme	The 2-4-2-1 Scheme
0	0000	0000	0000	0011	0000
1	0001	0001	0001	0100	0001
2	0010	0010	0010	0101	0010
3	0011	0011	0011	0110	0011
4	0100	0100	0100	0111	0100
5	0101	0101	1000	1000	1011
6	0110	0110	1001	1001	1100
7	0111	1000	1010	1010	1101
8	1000	1001	1011	1011	1110
9	1001	1010	1100	1100	1111

Each of these schemes has some advantages and some disadvantages, and its use depends on the circumstances, and what the design engineers desire most to gain.

Each binary digit in the code for a decimal digit is regularly expressed by a separate unit of hardware in the computing equipment, such as one electronic tube in a set, one wire in a group, one channel on a tape, etc.

Hexadecimal Notion

Coded decimal notation uses ten out of sixteen possible binary combinations of four binary digits. In order not to waste the six unused combinations, and for other reasons, *hexadecimal notation,* or notation in the scale of sixteen, has been used in one computer (SEAC). The hexadecimal digits written in ordinary language are the digits 0 to 9 and a choice of six letters, such as t for ten, e for eleven, d for twelve (dozen), h for thirteen, f for fourteen, and i for fifteen.

Numeric and Alphabetic Coding

For some computers, all information must be converted into numbers in order to be expressed. For example, places such as Boston, New York, Philadelphia, Washington, etc., will be labeled as decimal digits 0, 1, 2, 3, ... and their presence in an item of information will be labeled. This is *numeric coding,* a system of coding or abbreviation such that all information the machine is to handle is reported in numbers.

But for some computing equipment this is not necessary. In at least one computer (Univac), and in punch card machinery, there exist also codes for letters and punctuation as such. Thus, the places could be labeled BS, NY, PH, WA, ..., and these labels as such would be acceptable to the computing equipment. This is *alphabetic or alphameric coding,* a system of coding or abbreviation such that information for the machine to handle may be reported not only in digits but also in letters.

Logical Design of a Digital Computer

So much for the form of information in order that it may be acceptable to a computer. Now, how does a computer take in information and operate upon it?

The answer to this question is the logical design of the computer, its design in regard to the logical and mathematical meaning of the associations of the hardware. Curiously perhaps, nearly every automatic digital computer has identically the same basic logical design. It consists of the five units and two channels shown in Figure 1.

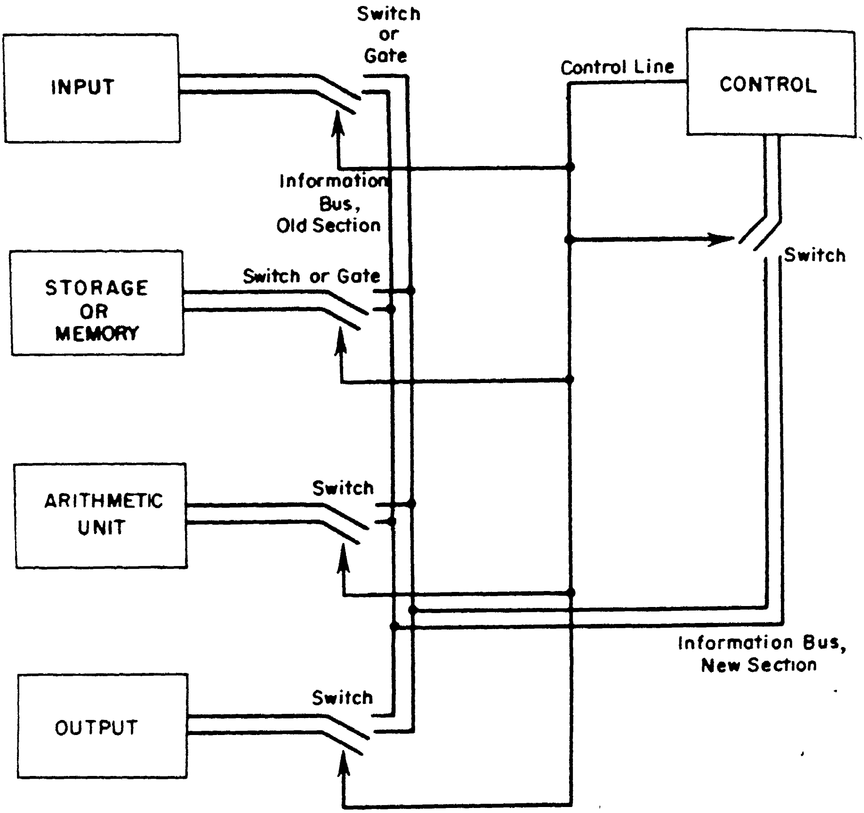

Figure 1. General scheme of an automatic digital computer. The information bus is assumed to consist of two lines along which numbers of two binary digits flow.

The *input unit* is the point where information is received from the outside world expressed in *machine language,* information in the physical form which the machine can handle and operate hardware with, such as punched paper tape.

The *storage* or *memory unit* consists of a large number of locations or registers (as many as 1,000 or 10,000) where information is stored or "remembered," available for use.

The *arithmetic unit* is the place in the machine where information is operated on arithmetically or logically.

The *output unit* is the point where information is given back to the outside world, usually converted into forms that can be read easily by human beings, such as printed characters on paper.

The *control unit* is the unit that controls the switches or gates that connect specific registers in the units to the information bus, and so controls the sequence of operations in the computer.

The *information bus* is a channel, usually one or more wires, along which information flows in the form of a pattern of signals.

The *control line* is another channel, usually a single wire, along which the successive control signals flow, opening or shutting switches or gates.

Operations in a Computer

In general all operations in a computer either transfer information or modify information. Every transfer operation in the machine is basically equivalent to:

1 – connect the sending register to the information bus;
2 – connect the receiving register to the information bus;
3 – transfer the pattern of information in the sending register to the receiving register.

Every operation that modifies information is basically a result of the fact that some registers (those in the arithmetic unit) have the property that the information they send out is a combination or transformation of information received earlier.

The maximum speed for a transfer would be the speed of an electromagnetic wave, 100 feet in a ten-millionth of a second. Actual speeds are considerably slower, perhaps around 10 feet in the same time. The preparatory opening and closing of the switches under the influence of the signals in the control line is much slower still, and takes appreciable time, which is ordinarily measured in *milliseconds* (thousandths of a second) or *microseconds* (millionths of a second). An operation that modifies information may take considerably longer than a transfer.

Around 1946 or 1947, it was generally realized that the machine could compute many of its own instructions, if a "new section" of the information bus running to the control unit was inserted. This has now become standard, and information calculated by the machine may flow into its own control unit, and thus guide the machine in its actions on future stages of the problem.

Cycles

In order for operations with information to proceed systematically, a digital computer operates in cycles. A *cycle* may be defined generally as the smallest period of time and process that repeats itself; in a computer, ordinarily, a cycle consists of the period of time and process for the issuing of a command from the control unit, and the execution of the command throughout the rest of the machine.

In any electronic computer, a cycle will consist of a flow of *pulses,* sharp changes of voltage, from high to low or from low to high. The changes of voltage will be very rapid, often occurring in fractions of microseconds. The *repetition rate* is the fastest rate of pulses used in the circuits of the machine.

Serial operation is the flow of information through the machine or some part of it using only one line or channel at a time; *parallel operation* is the flow of information through the machine using two or more lines or channels simultaneously.

A *synchronous computer* is one where the performance of all ordinary operations starts with equally spaced signals from a master clock; this is *fixed cycle operation.*

An *asynchronous computer* is one where the performance of any operation starts as a result of a signal that the previous operation has been completed; this is *variable cycle operation.*

II:2 STORING INFORMATION, AND THE MEMORY UNIT

One of the tasks which computing machinery must perform is to store information, or *remember*. But how can a piece of machinery remember anything?

To begin with the simplest example, one's hand can store or "remember" the number two by turning two fingers up and folding the remaining fingers down. In the same way, an automatic computer can remember a piece of information by the relative arrangement of items of equipment. In fact, almost any physical medium can be used for storing information if it has or can be given at least two states. The history of writing is very largely the history of steadily improving means for storing information.

On a sheet of paper there is ordinarily no definite location for storing any particular piece of information. But in a machine it is convenient, useful and often essential to assign a definite location for each unit of information; such a location is called a register or *memory location,* and it regularly stores a machine word, a set of characters handled as a unit in the machine. An *address* is the name or number identifying a register or memory location.

Now in the case of a computer it would not do much good simply to store information without having easy ways for putting information into storage, taking information out of storage, and completely removing previously stored information so that new information may be stored using the same equipment. These three operations are called, quite appropriately, *writing, reading,* and *erasing.*

Mediums for Storing Information

The important mediums used in modern electronic digital computers for storing information are: surfaces or other hardware where magnetically polarized spots or areas may be arranged; small magnetic cores which can store a magnetically polarized state; surfaces where electrostatic charges may be arranged; and lines along which a circulating train of waves may be stored. Each of these mediums will now be explained.

Magnetic Memory

Storing information as a pattern of magnetically polarized spots on a surface is a development of lasting importance, because of the closeness with which the spots can be assembled on the surface and the permanence of the recording, coupled with easy change. It does have the disadvantage that no human being can tell by just looking what is the information that is stored. But this is a minor drawback.

A *magnetic drum* is a rapidly rotating cylinder, the surface of which has a thin magnetic coating on which information may be stored as small polarized spots.The size of the drum is generally 1 inch to 2 feet long, and 5 inches to a foot in diameter. The drum rotates at speeds up to 120 or 150 revolutions a second. In order to record or read or erase, a *magnetic head* is used. This is simply a small electromagnet usually with a gap between its pole pieces of about a mil (a thousandth of an inch), and positioned about one and a half mils away from the drum. Usually there is one head to each *channel* where spots may be recorded around the drum as it turns.

Occasionally a single head is moved longitudinally along the drum to record or read in more than one channel.

Magnetic tape is tape made of paper or metal or plastic, which is either coated or impregnated with magnetic material, on which polarized spots representing information may be stored. Reading, writing, or erasing is accomplished with much the same type of magnetic head. The density of information may be 200 spots per inch of length, with six to ten channels per inch of width. Since the tape may move as much as 15 feet per second, reading, writing, or erasing may be as fast as 10,000 decimal digits per second. Up to 1200 or 2400 feet of tape may be stored on a *reel* or spool of tape.

Magnetic core memory is a form of magnetic storage where information is stored as the polarization north-south or south-north of a wire-wound core. Considerable experimentation has led to smaller and smaller cores with fewer and fewer turns of wire down to a single wire passing through a toroidal core. They may be arranged in three-dimensional arrays, and such assemblies of magnetic cores are a remarkably useful form of computer memory.

Magnetic wire is wire coated with or made of magnetic material on which polarized spots representing information may be stored. Since magnetic wire furnishes only one channel in which information can be stored, and is also subject to more tangling than magnetic tape, it is almost obsolete for computer memory.

Electrostatic Memory

A second important medium for storing information in an electronic computer is a surface on which electrostatic charges of two different kinds may be maintained. For example, such a surface may be the screen of a large electronic vacuum tube, called a *cathode-ray tube,* such as the picture tube in a television set. On this screen, information may be stored as the presence or absence of small localized electrostatic charges. The capacity of the tube is usually 256, 512, or 1024 spots. With some screen coatings, a charge placed on a certain spot of the screen will remain even with no further power for as long as five minutes, and sometimes longer. Since an electronic computer may perform 1000 operations in a second, five minutes is for a computer a relatively long time.

The charge is stored in the form of a small heap of electrons on a small part of the surface of the screen and is therefore subject to scattering: the electrons will have a tendency to wander away and be lost as a result of time and as a result of "reading" the charge. In particular, when information is being recorded and then read or erased on a neighboring spot, the charge on the given spot tends to fade quickly. Consequently, it is necessary to *regenerate*, or restore, spots of charge. This may be accomplished by spraying them with electrons in what is called a *holding beam*. The *read-around-ratio* is the number of times that information can be recorded or read or erased successively as an electrostatic charge on a single spot on the screen, before the charge on neighboring spots must be restored if not to be lost.

Delay Line Storage

A third important form of storage of information in an electronic computer is known as the delay line. A *delay line* is a device which stores information in a train of waves, as a pattern of the presence or absence of pulses. An example of a delay line in everyday life is an *echo;* the air and a reflecting wall momentarily store a train of sound waves. In a delay line to be used in a computer it is necessary to detect the waves issuing from the far end of the line, amplify them, reshape them, and reinsert them into the beginning of the line, so that the whole train of waves with its pattern of presence and absence of pulses will circulate indefinitely until either the power ceases or a new pattern of pulses is inserted.

There are in general two types of delay lines. An *electrical delay line* makes use of electrical pulses in an assembly of coils and capacitors. The speed of the train of waves is rather fast; an electrical delay line has to have considerable length to store even half a dozen pulses, and they come out at the far end rather blurred. A *sonic delay line* or *acoustic delay line* makes use of pulses in the molecules of a physical medium, which may be solid – quartz for example – or may be liquid – mercury for example. Quartz and mercury delay lines are common. Sometimes the delay line is a rod or pipe several feet long; sometimes it is a box or irregular polygonal block, the paths being reflected internally off the boundary surfaces. Such delay lines will store trains of a thousand pulses, with very little blurring; but the temperature of a mercury delay line must be maintained rather accurately. A *mercury tank* is a container of mercury holding one or more delay lines storing information; and the *mercury memory* in a computer consists of all the delay lines using mercury as the medium for storage of information.

Access to Memory

One of the important measurements of memory in a computer is the time required to read a desired piece of information out of the memory. This time is called the *access time*.

The access time will be on the order of 12 microseconds with electrostatic storage. For example the 113th spot in each one of 40 cathode-ray tubes can be read in the sum of two times: (1) the time to position the electron beams for reading; (2) the time to read out the information.

The average access time will be on the order of two or three hundred microseconds in the case of a mercury delay line containing perhaps 60 machine words. It is necessary to wait until the desired word arrives at the exit end of the loop, is there detected, and then routed into the computer for use. Access time will be much longer still in the case of a reel of magnetic tape, for the desired information may be three-quarters of the reel away. Access time is therefore an important consideration in the usefulness of a computer.

The time of access to the memory may be reduced by careful arrangement of the sequence of references. But this is troublesome. In general, the problem of speeding up reference to the memory of a computer is solved by dividing the memory into two or three parts: the *rapid memory*, with very swift access; the *slow memory*, for which access is relatively slow; and, in some computers, *intermediate memory*, for which the access time is in between. For example, the rapid memory might consist of 1000 registers of electrostatic storage; the slow memory, of 500,000 registers of magnetic tape storage; and the intermediate memory, of 10,000 registers of magnetic drum storage.

Random access is access to memory under conditions where the next register from which information is to be obtained is chosen at random. For example, access to names in the telephone book is random access; the next name that anyone is going to look up may be almost anywhere in the book with roughly equal probability. The general application of electronic computers to business, commerce, and industry depends to a great extent on the development of a random access memory which is both large and efficient. So far, the ordinary card file with millions of cards has no good computer equivalent. In fact, an entirely new level of efficacy in automatic computers will be reached, when, instead of a million registers of memory most of which is slow, the computer will have a billion registers of rapid memory.

Addressed memory is memory where each individual register bears an address. Rapid memory regularly is addressed memory. In storage of information on magnetic tape, and often in other mediums also, only blocks of items of information will have addresses. Within any block the identification of the desired item of information depends on counting forward from the beginning of the block.

Internal memory is the total memory which is accessible automatically to the computer without human intervention. *External memory* is information stored in machine language outside the machine, as, for example, recorded magnetic tape in a closet, or punch cards in filing cabinets.

Permanent memory is memory in which recorded information stays when the power is turned off in a scheduled fashion, as, for example, a magnetic drum. If the power is turned off in an unscheduled way or if power is interrupted, transient voltages may occur resulting in spurious pulses that can be very troublesome. *Volatile memory* is memory having the property that if the power is turned off, the information vanishes; for example, delay line memory is volatile.

II:3 CALCULATING AND THE ARITHMETIC UNIT

The *arithmetic unit* of a computer is the section where arithmetical or logical operations are performed on information. Incidentally, the word "arithmetic" in this expression is accented on the "et," like "ascetic."

This unit often consists of three registers and associated control circuits. The first two registers receive the *operands,* or numbers operated on, and they are often called the *A* and *B registers*. The third register is often called the *accumulator* or the result register, and is the register where the result of arithmetical or logical operations is first produced. But the actual arrangement varies from machine to machine, for there are many ways in which the necessary operations may be carried out. Some registers may be *counters* – a mechanism or circuit which either totals digital numbers, or allows a digital number to be increased by additions of one in any column or place of the number.

Arithmetical Operations

The arithmetical operations of a computer, of course, include addition, counting, subtraction, multiplication, and division, but also include shifting, complementing, truncating, rounding off, double precision operations, and more besides. *Shifting* means multiplying or dividing a number by a power of the base of notation (usually ten or two); for example, 1010 shifted two places to the left gives 101000. Shifting is regularly performed as a special rapid operation, much faster than the usual multiplication or division. The *complement* of a number in decimal notation is the number obtained by replacing each decimal digit by nine minus that digit; for example, the complement of 734 is 265. The *complement* of a number in binary notation is the number obtained by replacing each digit by one minus that digit. For example, in binary notation, the complement of 11010 is 00101. A number may be subtracted by adding its complement and then adding unity in the extreme right-hand column or place of the number. The circuits by means of which the one is added may be specially designed in different ways, depending on the designation in the computer of plus and minus signs and positive and negative numbers.

The *precision* of a number is the degree of exactness with which it is stated, while the *accuracy* of a number is the degree of exactness with which it is known or observed. The precision of a quantity is reported by the number of significant figures in it. For example, in the statement "The power required for the computer is 55.7843 kilowatts," the number is precise to six figures, but its accuracy is known to be far less.

The expression *double precision* refers to computations that use twice the ordinary length of machine words. For example, in the case of a desk calculator handling 10-place decimal numbers, computing with 20-place numbers by keeping track of the 10-place fragments is computation with double precision.

Truncating means lessening the precision of a number by dropping digits. For example, the number π, 3.14159265...., is truncated to four figures in 3.141. Truncation of unending numbers like π is inevitable in a digital computer. *Rounding off* means changing a precise number to a less precise one, ordinarily choosing the nearest less precise one with a given number of significant figures. For example, π *rounded off* to five significant figures or four decimals is 3.1416.

Questions of truncation and rounding off are important when using digital computers, because as yet there is no definite rule about how many figures a calculation must employ in order to be certain of a given number of significant figures at the end of the calculation. For example, in ordinary computations, calculating with ten significant figures and expecting to have seven significant figures at the end is a reasonable assumption. But it is easy to contrive calculations with ten significant figures in which there are no significant figures at the end of the calculation. With thousands of operations a second in a digital computer, even in a few minutes problems of truncation and roundoff may become serious because of the building up of errors.

Range of Numbers

A computer, like a human being, regularly is able to handle numbers in only a limited range of magnitude. For example, the computer called the Bell Model V is able to handle numbers in the form $\pm a \times 10^b$ where a is any number in the range .1000000 to .9999999 and b is any number in the range -19 to $+19$. A number smaller in absolute magnitude than any of these numbers is the machine's idea of *zero;* a number larger in absolute magnitude than any of these numbers is the machine's idea of *infinity;* and the Bell computer contains circuits enabling it to respond appropriately to these two special numbers.

The range of numbers in some machines is much more limited still: several computers will handle only fractions between plus one and minus one, and one computer will handle only whole numbers and no fractions. This feature of a computer requires that a problem, before it is put on such a machine, must be examined for the maximum or minimum size of numbers which can occur in each step of the problem. A *scale factor* is a factor used to multiply or divide quantities occurring in a problem, so as to convert them into a desired range of magnitude so that a computer can handle them. *Scaling* is the process of applying scale factors, and sometimes is a little troublesome. But it is essentially little different from many operations done manually in the course of solving problems, for example, when division by a quantity close to zero must be avoided.

Fixed-point operation in a computer is operation assuming a fixed or constant location of the decimal point or the binary point, in each register of the machine. Some computers calculate in this way for reasons of simplicity of hardware. Shifting of numbers from time to time may be necessary in such a computer. *Floating-point operation* is operation using a variable location of the decimal point or binary point. It consists of writing each number by specifying separately its coefficient, its exponent, and its sign. For example, in floating-point operation, the number 6.04×10^{23} might be reported in a ten-place register as +6040000023 or +2360400000.

Logical Operations

An automatic computer which performed only arithmetical operations would be barely useful, certainly hardly any more powerful than a desk calculating machine. But automatic computers also perform logical operations, and this property renders them so powerful that limits of their capabilities are hard to imagine. What do we mean by logical operations?

Logical operations mean operations such as comparing, selecting, referring, sorting, collating, etc., where in essence reports about statements corresponding to yeses and noes affect calculating operations.

Comparing, considered as a logical operation, consists of determining whether two pieces of information, usually numbers, are the same or different. The computer contains an operation or circuit which will give out a signal depending on whether the two items are equal or unequal. Since the signal needs to be available to the computer for further computation, it is usually recorded in a register as a one or a zero, corresponding to a yes or a no.

Selecting is the logical operation of taking item A if the report on a certain condition P is yes, and taking item B if the report on P is no. Again, many circuits exist which will carry out this operation; and such a circuit may be called a *selector* or *selecting circuit.*

Referring is the operation of entering a file or reference book with a given item of information, and finding a corresponding desired item of information. In mathematical language, it is the operation of looking up in a *table* (or *function table*) the value of a *function* corresponding to the value of an *argument.* In one sense, all mathematical operations may be reduced to this single one, for in the last analysis even arithmetic is based on referring to tables of results of counting, adding, and multiplying.

Sorting is the operation of arranging items of information in groups according to previously chosen classes of items. *Sequencing,* another logical operation, is selecting A if A is greater than or equal to B, and selecting B if A is less than B, or some variation of this. *Merging* is combining two sequences of items of information in a way such that the same sequence is maintained in the combined sequence. For example, sequence 12, 29, 42 and sequence 23, 24, 48 may be collated into 12, 23, 24, 29, 42, 48. *Matching* is an operation of comparing two sequences of items of information, selecting those that are alike in stated respects, and rejecting those that are unlike. *Collating* includes merging and matching, and other similar operations of assembling and comparing sequences of information.

Another logical operation present in some computers is *extracting:* the operation of obtaining certain digits from a machine word as may be specified. For example, if the ten-digit number 00000 11100 is stored in a machine register, the computer can be instructed to "extract" the eighth digit (in this case a one) and correspondingly perform a certain action. This operation, together with shifting, enables logical information expressed in ones and zeros to be stored much more compactly than if each such piece of information required a whole register to itself.

Another useful operation is *overflow,* in a counter; this is the production of a number in the counter which is beyond its capacity, giving rise to a carry signal that can be employed for useful purposes. This would happen for example in a six-place counter holding 999784 if 4000 were added.

The study of possible, interesting, and useful logical operations in automatic digital computers has received a considerable impetus in the last few years from the existence of such computers. Not only do logical operations apply to the numbers or other information which computers receive from the outside world, and manipulate; but also they apply to the instructions which themselves govern the computer. More will be said about this in the next chapter. Basically, the study of logical operations in computers is part of a larger study known as symbolic logic. *Symbolic logic* is essentially a science which studies exact reasoning and operations, expressed by such words as AND, OR, NOT, IF, THE, OF, ..., concentrating mainly on nonnumerical relations, and using symbols that are efficient in calculating.

Speed of Operation

In modern electronic computers, arithmetical operations are carried out at high speed. Additions commonly are performed at rates of 1000 to 5000 per second, and multiplications at rates of 500 to 1000 per second. Different manufacturers of computers, however, use different and noncomparable methods to report their operation speeds. Accordingly, it is convenient to define what may be called a representative calculating operation. A *representative calculating operation* is an operation equivalent to the average of nine complete additions and one complete multiplication, where any one of these complete operations includes obtaining the instruction and the two operands out of the rapid memory, performing the operation, and putting the result back into the rapid memory.

II:4 PROGRAMMING AND THE CONTROL UNIT

Program

In order to get a general purpose automatic computer to do anything at all, such as solve a problem, or prepare information in a form suitable for printing, or arrange given data in a new order, the automatic computer must, like a clerk or a printer or an accountant or a mathematician, be instructed what to do. In order to instruct the computer, a sequence of instructions, orders, or commands is put into the machine, and the machine performs them. The sequence of instructions is ordinarily called a *program.*

Other terms for "program" are *routine* or *sequence of instructions*. The words *subprogram* and *subroutine* apply more particularly to a part of a program, a short or repeated sequence of instructions for a machine to solve a part of a problem. The instructions for the machine have to be translated into a language acceptable to the machine and this language is often called the *code* or *machine code.*

Programmer, Codes, and Operator

A *programmer* is a person who prepares for the computer sequences of instructions adapted to the solving of a given problem. The programmer does not necessarily convert the instructions into the detailed machine language or codes acceptable to the machine —this duty is the function of the *coder,* who is a person who translates a sequence of instructions into the precise codes acceptable to the machine. Of course, in many laboratories programmer and coder are the same person. An *operator,* on the other hand, is a person who actually operates the computer, puts problems on and off, presses buttons at the right times, etc. He may or may not (and usually does not) understand the program but he often understands many of the codes.

Form of a Program

The form in which an automatic computer takes in most or all of its instructions—its program—may be a paper tape, a magnetic tape, a stack of punch cards, or a plugboard. A *plugboard* is a removable board holding many hundreds of electric terminals into which short connecting wire cords may be plugged according to different programs for the machine.

A *program tape* is the tape which contains the sequence of instructions to the computer for solving a problem. Another (obsolescent) name for it is *sequence-control tape.*

To change a program, one tape or stack of cards or wired-up plugboard is removed and another inserted. Clearly, in many cases it will be better and easier to prepare a program by punching or marking tape than by wiring up a plugboard. Also, it may be easier to change a program by changing tape or cards than by switching to another plugboard.

Comparison of a Tape and a Plugboard

A tape contains a sequence of instructions that the computer will act on, one after another. A plugboard, on the other hand, contains simultaneously all the instructions that will apply to each case or problem that passes through the machine. It requires a moment's reflection to see that the two forms of program are basically similar; this is true because as different cases or problems, represented by different punch cards, or different areas of recorded tape, pass through a computer using a plugboard, they include within themselves certain punches or codes that cause the selection of the appropriate one of the set of instructions all wired into the same plugboard. But it is also clear that the tape is likely to be more general and more flexible because it takes less work to record the presence or absence of a character on the tape than the equivalent presence or absence of a wire in the plugboard. In addition, the tape is almost unlimited in capacity whereas the plugboard is rather sharply limited.

The Nature of an Instruction

A single *instruction* recorded on the program tape is a machine word or set of characters which conveys to the machine an action to be taken. Other words for instruction are *command, order,* and *program step.* A *coding line* is a single command or instruction written usually on one line of the program tape, expressed in machine language, and part of a program for solving a problem.

The fullest form of an instruction for an automatic digital computer is "Take out the information in register M. Also take out the information in register N. Perform the operation O. Store the result in register P. Then proceed to take the next instruction out of register Q."

How does a computer carry out a command like this? The command is entered as information in what is called the *control register* or *program register* of the computer. The *program register* is located in the control circuits of the computer and is the register which stores the current instruction of the program and thereby completely controls the operation of the computer during the cycle of execution of that instruction. We can imagine the computer to be like a railroad with many sidings; the program register is a control tower which connects or disconnects any siding to the main line; information, in carloads, is dispatched swiftly through the system, starting from a siding loaded with information and entering any siding which is connected to the rail line ready to receive information. The program register has the property that the information in it opens or closes, connects or disconnects, any register in the machine to the bus, the main channel in the computer along which information flows.

By various arrangements of logical design in a computer, it is possible to split up the standard instruction in fullest form. For example, "transfer into" may be treated as an operation, "transfer out of" may be treated as another operation, and a fixed register, often called the *accumulator* may be referred to in every command; then, the instruction in fullest form which mentions four registers, can be reduced to an instruction which mentions three or two or only one register. This gives rise to the systems of programming which are called respectively *three-address, two-address,* and *one-address.* For another example, instead of specifying in each command the register where the next instruction is to be obtained, it can be understood that the next instruction comes from the register next following the one which provided the current instruction – except when an operation "transfer control to" causes a change to the instruction in a new register.

Complete Operation

Under these conditions it can be seen that different computers may be rather hard to compare. For example, one computer can perform 14,000 single-address instructions in a second; another can perform 4000 four-address instructions in a second; which is faster? In order to make a valid comparison between computers, the concept of a *complete operation* is used. A *complete operation* is a calculating operation which includes obtaining all the numbers entering into the operation out of the memory, making the calculation, putting the result back into the memory, and putting the next order into the program register ready for execution. A representative calculating operation (see the last chapter) makes use of nine complete additions and one complete multiplication.

Machine Language

Part of the translation of a problem into language acceptable to the machine involves what are called *alphabetic coding* and *numeric coding.* Some machines are limited to the extent that alphabetic information must be converted into codes expressed in numbers before the information can be inserted into the machine; for example, four places such as Boston, New York, Philadelphia, Washington, would have to be coded, say, 0, 1, 2, 3. Other computers, however, will accept alphabetic characters; in that case, abbreviations such as BS, NY, PA, WA or B, N, P, W would be acceptable to the machine. This is spoken of as *alphabetic coding.*

Closely related is the problem of what kind of numbers will be acceptable to the machine, some machines accepting only decimal numbers, others accepting only binary numbers, some accepting either. The problem of conversion is usually given to the computer; the mathematical process of conversion from decimal notation to binary notation is programmed and performed by the computer, and so is the reverse process, of conversion from binary notation to decimal.

In business and commercial arithmetic, a machine that operates in decimal or coded-decimal notation is almost essential. For, converting each of the two numbers into binary notation, adding them, and then converting the result back into decimal notation involves much unnecessary mathematical computing. Furthermore, if the operation of rounding off in binary notation occurs, the result may be a penny or two different when one returns to decimal notation; this would be highly undesirable in most cases.

Types of Programming

The preparation of a program for a problem leaves rather a good deal of leeway to the programmer. The methods by which the problem may be solved are often numerous. The choices of first approximation for a procedure of successive rapid approximation are numerous. The ways in which machine registers may be assigned in order to carry out the program are numerous. And there are many other choices. Consequently, there is a lot of room for good programming and bad programming.

The time that a computer requires to carry out a program is often governed by the fact that the different registers of the memory are not all available with the same waiting time. *Random access programming* consists of programming a problem for a machine without regard to the time for access to the information in the registers called for in the program. *Minimum access programming* consists of programming for a computer in such a way that there is a minimum loss of time in obtaining information out of the memory; this is also called *minimum latency programming*.

Programming has become a considerable bottleneck in the use of some computers. As a result, much effort has gone into devising ways for the automatic machine itself to take over some of the load of the programming. At the Harvard Computation Laboratory, a "coding machine" has been devised, which takes ordinary mathematical expressions in almost their ordinary form and converts these into the particular chain of very simple commands which a computer may require.

In the Eckert-Mauchly Division of Remington Rand Inc., a great deal of progress has been made in the direction of the self-programming computer, largely due to the work of Dr. Grace M. Hopper. Some of this progress is reported in the chapter on the Univac. A *library of routines* — a collection of programs or routines by means of which many types of mathematical problems may be solved — is first set up. In fact, copies of subroutines on punch cards may be obtained. Then *compiling routines* enable the machine itself to select programs out of its library and string them together to assemble a special program for the solution of a given problem. In one instance, the time for the computer to assemble a program was 1½ minutes, whereas the corresponding time for a human programmer was about 16 hours. Furthermore, the machine-assembled program was correct, whereas the human programmer's program inevitably contained a few errors. The point of view being pursued is the *education of a computer* (a phrase due to Dr. Hopper) — preparing and assembling programs and devices for a computer so that the computer can itself put together and devise many programs for many purposes, thus greatly reducing the time required from human programmers to program the computer.

II:5 THE INPUT AND OUTPUT UNITS

In order for an automatic digital computer to be fully useful, careful consideration needs to be given to its equipment for input and output of information. Several of the earlier automatic digital computers suffered from lack of balanced design in this respect: computation inside the computer was very rapid, but input and output were quite slow; even some of the latest automatic computers suffer to some extent from the same inadequacy. Of course, a great deal depends on the user's requirements as determined by the types of problems he has to solve.

Input Information

Essentially, there are three basic kinds of information from the point of view of the input operation. The first kind is information that a human being knows, and that he needs to convert into some form acceptable to an automatic computer. If the human being uses fingers and a keyboard, then a high average speed for this process is 2 or 3 characters per second, which is equivalent to an input rate of 15 to 20 binary digits per second.

The second kind of information is that which an instrument observes (such as a physical variable) and which is converted by a mechanical device into a form acceptable to the automatic computer. If we consider modern apparatus designed especially for this purpose, an average speed for this process may be estimated as 1000 samples or observations of the physical variable in each second, each observation of three decimal digits accuracy. This is equivalent to an input rate of about 10,000 binary digits of information per second.

The third kind of information is information obtained at an earlier time and stored outside of the computer but in machine language. A high average rate of speed for input of externally stored information of this kind is 10,000 characters per second, which is equivalent to a rate of 60,000 binary digits per second.

It is at once clear, therefore, that input to an automatic computer should as much as possible avoid the human being, since he is a serious bottleneck. It is also clear that if a human being is inevitably required to prepare input, then the input he produces should be carefully stored in a machine language to avoid all delays after the initial one. For example, for some time to come, human beings will be required to prepare parts of programs of instructions. Therefore the whole program for a given problem should if possible be assembled by the machine and fitted together by the computer calling on previously prepared stored subroutines suited to the problem in question.

Now, suppose that an automatic computer performs 1000 representative calculating operations a second, each involving three numbers say of 40 binary digits. Then, roughly, information is flowing through the arithmetic unit of the computer at a rate of 120,000 binary digits per second, but of course, a good deal of the calculating going on in the arithmetic unit is with intermediate results and not with input. Suppose, for the sake of illustration, that the proportion is 20 intermediate results being used for each item of input information used. Then the computer will only be able to process about 6000 binary digits of input information per second, and the insufficient speed of the calculating unit will become the limiting factor on the production of the computer.

Input Devices

The mechanisms and devices which accept actions by human beings and produce machine language, a form of information acceptable to the computer, are:

- –the key punch, which receives impressions on a keyboard, and produces punched cards or punched paper tape;
- –the keyboard magnetic tape typer, which receives impressions on a keyboard and produces recorded magnetic tape.

Both are limited by the speed of the human being, and by the likelihood of human mistakes.

The information recorded by the human operator must be verified. Verification is a long and costly process, usually requiring two separate recordings, mechanical comparison of them, detection of errors, correction of them, and verifying the corrections. A *punch card verifier* is a card machine operated manually which reports by signals whether punched holes have been inserted in the wrong places or have not been inserted at all.

Mechanisms which accept observations of a physical variable and produce language acceptable to a machine are many and varied. One for example is a modified *strain gage*. This consists of an instrument which will observe and measure the amount of strain or force being exerted on some object being tested, coupled with a device for converting from analog to digital form; and this device in turn will cause a punch card to be punched digitally with the reading of the amount of strain.

A device currently in an advanced state of development is an *electronic reader* of printed characters and numerals. One such machine, made by Intelligent Machines Research Corporation, Arlington, Virginia, uses a technique from television circuits known as the *flying spot scanner*. This machine "examines" a small area of a surface and notes whether points on the surface are dark or light; it assembles the information into "shapes" and compares the shapes observed with shapes stored in its memory; and it recognizes printed letters and numerals. This input device promises to revolutionize the conversion of language acceptable to human beings into language acceptable to machines.

Mechanisms that accept a stored form of machine language and give information to the computer are:

- –punch card reader, using electrical or mechanical sensing;

—punch tape reader, using electrical, mechanical, or photoelectric sensing;
—magnetic tape readers;
—photoelectric tape readers.

A *card reader* (or tape reader) is a mechanism that causes the information in cards (or tape) to be read electrically or mechanically, usually by passing under wire brushes, across metal fingers, or under magnetic heads.

The basic input devices, of course, are multiplied by variations in style between different manufacturers. For example, at least three kinds of punched paper tape are in use, according to the number of holes in a row across the tape (5, 6, or 7). Also, there is paper tape without chaff, in which the holes are not totally punched but only partially, and the punched area is left hinged on one side of the hole (chaffless tape).

Also necessary are machines which can change one kind of machine language into another. A converter is a machine which changes information in one kind of machine language into corresponding information in another kind of machine language. For example, a machine which takes in information expressed in punch cards and produces the same information expressed in magnetic tape, is a converter. Often such a machine possesses limited computing facilities, spoken of as *editing facilities*. The important cases are converters of punch cards, paper tape, and magnetic tape, each into the other.

Output Information

In the same way as with input information, there are three basic kinds of output information: information transmitted to a human being, which he will use to answer questions or make decisions; information transmitted to a control device or process actuator, as, for example, an aileron in an airplane or a valve in a pipeline; and information which is stored either in machine language or language humanly readable for later reference.

The speed at which a human being can take in information put out by any source is hard to define or measure, but it is not great. Most human beings have considerable trouble absorbing more than one or two pieces of information, "yes-noes," per second, and certainly cannot keep up that speed for many seconds. From the point of view of a human user of the information put out by an automatic computer, the machine should be programmed to tell him exactly what he wants to know, and give him not more than a dozen or so pieces of information to be used during several minutes. Often graphic display on an oscilloscope or on a plotting board meets this requirement.

A control device or process actuator can accept information at a much higher rate, within limits. The rate might be 100 signals per second, each consisting of three decimal digits, which is equivalent to a rate of 1200 binary digits per second. Of course, the device may have physical inertia in its mechanism, causing it to refuse to accept within a short time changes exceeding certain limits. But in general, an automatic computer will be able easily to furnish an automatic controller, such as an automatic pilot, sufficient information to keep it "on the beam."

The speed at which an automatic computer can produce and store information for later reference may be as high as 10,000 characters per second if magnetic tape is used. This is equivalent to 60,000 binary digits per second, and is likely to be ample for many problems; but the form of storage is magnetic tape. To produce and store information in humanly readable form, a high average speed currently obtainable is in the neighborhood of 1000 characters per second.

Output Mechanisms

The mechanisms and devices which may produce or hold output information are:

- magnetic tape, recording polarized spots;
- punched cards and punched paper tape;
- photographic recording of the trace of an electron beam on an oscilloscope;
- photographic recording of light and dark spots on a panel of lights;
- photographic recording of characters formed on the screen of an oscilloscope;
- electric typewriter, typing one character at a time, with type bar striking the paper from the front;
- electric typewriter of the Varityper style, typing one character at a time, with hammer striking the paper from the back against the type matrix;
- line-at-a-time printer, which positions a whole row of characters on a whole row of type bars and then makes an impression, by striking the paper from the back against the type matrices;
- surface-at-a-time printer, which forms several rows of characters

simultaneously, as for example from a matrix of wire points, usually 5 by 7 to each character, and then makes an impression by striking the paper from the back against the wire points.

These mechanisms also have many variations according to the manufacturer. Currently, much research is pouring into this field, because of business demands for rapid printing of results, as, for example, the preparation of premium notices in a life insurance company.

Association of Input and Output Mechanisms with a Computer

In nearly all cases, no logical obstacles in theory prevent the use of any kind of input or output mechanisms with any kind of automatic computer. The meaning of information can, of course, be the same, whether it is presented as a pattern of holes in a punch card, or a pattern of polarized spots on a magnetic surface, or the pattern of a curve sketched by a beam on the screen of an oscilloscope. The physical obstacles to making such flexibility complete are often important but are steadily being removed, as more and more methods of translating any kind of machine language into any other kind are incorporated into physically existing and functioning devices. Such devices either come with the machine when it is obtained, or may be acquired at a later time.

II:6 RELIABILITY: CHECKING AND MAINTENANCE

One of the important properties of an automatic computer is *reliability*, the property of giving answers that can be relied upon as correct. Now a fast computer can perform 10,000 representative calculating operations in a second and there are 3600 seconds in an hour; so in an hour, such a computer can perform over 35 million operations. But even a little error can render the result uncertain, and a big error can render it entirely useless. Therefore it is necessary to design the computer, and the system in which it is used, so that the probability is excellent that no error will occur during the hour.

Types of Errors

The answer that a computer gives to a problem is subject to many types of errors, of two main kinds, human and machine. For a human error, an operator can press the wrong button; or a mathematician can program the problem incorrectly; or a clerk can key-punch incorrect data; etc. Great are the opportunities for human errors. It is fair to say that more than half of the erroneous answers produced by automatic computers are due to errors by human beings in contact with the computer.

Most machine errors are due to either steady or intermittent failure of some component. The steady failures are comparatively easy to locate and remove, compared with the intermittent failures, which often become famous as illusive "bugs" somewhere inside the computer. Some machine errors are due to defective design. A *program sensitive error* is an error arising from the unforeseen behavior of some circuits, discovered when a comparatively unusual combination of program steps occurs.

Checking

A number of kinds of checking, or verifying of the correctness of operation, are used in automatic digital computers. They are the outcome of a great deal of thought and engineering attention, devoted to obtaining the utmost reliability from computers.

Programmed checking is a system of checking with three features. First, before running any problem on the computer, a sample problem of the same type is run on the machine, and proved correct. Second, mathematical verification of operations are included in the program. For example, if A times B is performed at some stage, shortly afterwards B times A is performed; the two results are then compared, and if they do not agree, the machine signals an error. Finally, the person who is paying for the problem to be solved has agreed to be satisfied with a very high probability of a correct answer, instead of certainty.

Automatic checking is provision within the machine for automatically verifying the information held or transmitted by any device. Automatic checking is *complete* when every process in the machine is checked; otherwise it is *partial*. The *extent of automatic checking* means either (1) the relative proportion of machine processes which are checked, or (2) the relative proportion of machine hardware devoted to checking. For any kind of automatic checking, some 20 to

50 per cent more hardware is built into the computer to check every operation (at least partially) in such a way that the probability of a wrong result being allowed to come out of the machine is as remote as the probability that water will run uphill.

One of the methods of partial automatic checking is to carry along with each machine word some extra binary digits, called *check digits,* which report information about other *information digits* in the word. For example, the check digit may be 0 if the total number of binary ones in the information digits of the word is odd; the check digit may be 1 if the total number of binary ones in the information digits is even; this is called an odd-even check. Periodically, perhaps once every five seconds, the digits of every word stored in the machine may be added; if the total count of the information digits and the check digits is odd, the word is approved; if not, an error has occurred and the machine signals an error.

A *modulo n check* is a form of check digits, such that the number of ones in each number *A* operated with is compared with a check number *B* carried along with *A* equal to the remainder of *A* when divided by *n*. For example, in a "modulo 4 check," the check numbers will be 0, 1, 2, or 3, and the remainder of *A* when divided by 4 must equal the reported check number *B*, or a mistake has occurred.

A second method of partial automatic checking may be installed in the arithmetic unit of the computer. If two numbers *A* and *B* are added (or multiplied), then the check digits of their sum (or product) may equal the sum (or product) of the check digits of *A* and the check digits of *B*. An example of this is the check of an arithmetical multiplication known as the check by "casting out nines": the sum of the digits of the multiplicand modulo 9 is multiplied by the sum of the digits of the multiplier modulo 9, and the result modulo 9 is compared with the sum of the digits of the previously obtained product modulo 9. An *arithmetical check* is a check of a computation making use of arithmetical properties of check digits of this nature.

A third method of automatic checking may be installed in connection with every transfer of a number or a word in the computer. A *transfer check* is an automatic check that an operation of transferring a word has been correctly carried out.

Complete automatic checking means that every piece of information is stored in the machine in two locations, and that two arithmetic units perform each operation and comparison is universal. Thus in essence we have two automatic computers running in step with each other and comparing results. Every operation of the one computer is checked against every operation of the other. In practice this device is almost prohibitively costly; there exist only a few examples of computers with complete automatic checking.

Thus with adequate programmed checking or adequate partial or complete automatic checking, if the machine gives no error signals during the time that a problem is run, there is an excellent probability that the answer produced is correct.

Nearly all users responsible for issuing computed results prefer some automatic checking in the machine. But there are types of problems when a very high probability of a correct result is sufficient, and operation on this basis may be preferable to the loss of speed and increase of equipment usually involved in automatic checking. Besides, check circuits can cause errors too.

The Occurrence of Errors

If an error occurs, the machine may stop automatically, or else be programmed to stop, or be programmed to run the last instalment of the problem over again, determine whether the error is repeated, and if not, continue to run. In addition, the machine may be constructed in such a way that it automatically indicates the component of the machine where the error has been detected.

When an error does occur, usually nobody knows at the start what kind of an error it is.

A *post-mortem* tape may be run on the machine, which prints out the contents of every register, so that the mathematician may determine why his program "died" on the machine. Other types of error diagnosis tapes prepared ahead of time may be run, testing the performance of the registers, the arithmetic unit, the control unit, etc., indicating the units which do not test properly. Such tapes save a great deal of expensive computer operating time.

To deal quickly with machine errors, the maintenance crew needs to be well trained and provided with good drawings of the machine, and if possible an adequate key for swift diagnosis of any kind of error. The mathematician in charge of running the problem and the maintenance man in charge of the machine need to cooperate thoroughly too in order to find and remove errors. *Troubleshooting*, locating the cause of computer malfunctioning, and *debugging*, removing malfunctioning conditions from the computer or errors from the program, are frequently used terms. *Down-time*, in the operation of a computer, is the time when it is malfunctioning, or not operating correctly, usually because of machine failure.

The computer should be constructed using plug-in-units, so that if one unit turns out to be malfunctioning, it can be unplugged and another similar unit, which is a spare, plugged into its place. Then the offending unit can be repaired at leisure on the workbench or re-ordered from the manufacturer.

In the case of some computers, automatic indication of some faulty equipment can be installed; this will save a good deal of expensive time. But automatic indication of malfunctioning has not yet developed very far.

The Prevention of Errors

Most of the prevention of errors lies in careful training of the operators, the programmers, and the maintenance men. Mistakes that occur can be used as a basis of future training, so that they will not happen again.

To prevent some human errors, machines can be designed so that they are well adapted for contact with human beings; for example, the keys of a key-punch can be easy to press, instead of resistant, indicator lights can be located where they are easily seen, etc.

The fact that some proportion of machine errors has been due to the failure of electronic tubes has led to systematic checking of electronic tubes within the machine. For example, *marginal checking* is a system of designing the electronic circuits in a computer so that various parameters, such as the voltage of the heaters of the tubes, or the repetition rate of the machine may be changed or varied when desired for testing and the circuits then tested to determine if they still continue to operate satisfactorily.

Operating Ratio

For overall measurement of the reliability of a computer, the concept of *operating ratio* has been established, though defined in different ways in different places. One definition is the ratio obtained by dividing (1) the total number of hours of correct computer operation (even if the program is incorrect through human mistakes), by (2) the total number of hours that computer operation is attempted or could be attempted. For example, if the computer is scheduled for three shifts of operation totaling 120 hours in each week, and if so-called "preventive maintenance" takes 10 per cent or 12 hours, and "unscheduled down-time" is 2½ per cent or 3 hours, then the "operating ratio" is 87½ per cent.

Another concept for measuring the performance of a computer is *mean free time between errors*. Currently for many computers this ranges from five minutes to an hour, but better figures are anticipated before long. It is of interest to note that an hour's run at 10,000 representative operations per second is more computation than a human computer would perform on a desk calculator in twenty years.

Experience with large size automatic digital computers currently in service shows that the *operating ratio* may often reach 85 or 90 per cent. There may even be weeks when the operating ratio is 95 per cent. But this is not as good as can be desired. However, considering the novelty of automatic computers, the large number of parts, and the recency of the computer art, the operating ratio is surprisingly high. And it has resulted in a very large amount of useful work being turned out by automatic digital computers.

II:7 THE ADVANTAGES AND DISADVANTAGES OF AN AUTOMATIC DIGITAL COMPUTER

Advantages

The outstanding feature of an automatic digital computer is its extraordinary ability to solve problems; indeed it is probably the most efficient physical instrument for this purpose ever invented. Of course, the way in which a computer solves problems depends on how it is programmed by human beings, who make use of mathematical knowledge acquired during centuries of study.

There is no logical reason why a computer cannot be made to work in mathematical symbols instead of numbers. Some progress has already been made in this direction, notably by Harry Kahrimanian, who has programmed a Univac to find in mathematical symbols derivatives of elementary mathematical functions up to the 99th order. Also, there is no reason why a computer cannot develop new mathematical methods for solving problems, as soon as sufficiently general instructions are given to it.

Versatility

An important advantage of automatic digital computers is their versatility. They can be made in many different forms, sizes, capacities, and varieties, well adapted to solving many different types of problems. The varieties of problems found susceptible to attack by digital computers are continually increasing.

In the case of one new machine, the IBM 650, a magnetic drum automatic computer having a stored program and 2000 registers each holding 10 decimal digits, the combination of its properties is such that, before the first machine was delivered, there were orders for over 400 such machines on the books of the manufacturer, indicating its wide adaptability.

The versatility of an automatic digital computer is the result of its essential characteristics: a great many registers (often 500 or more) where information may be stored; and a flexible, branching control over the sequence of reasonable operations that it performs.

Comparison with an Analog Computer*

In comparison with an analog computer, a digital computer has in many instances some considerable advantages. An analog machine is likely to be particularly useful when (1) all variables entering the problem are physical quantities; (2) there is one independent variable which can be put into correspondence with time; (3) each problem to be solved has only one sequence of operations or program that applies to it; and (4) accuracy up to the three or four significant figures is sufficient. A digital machine is useful when (1) one or more of the variables entering the problem are on-off conditions or nonnumerical variables (such as names); (2) there is more than one independent variable; (3) the problem to be solved has more than one program or a branching program; and (4) accuracy of more than four significant figures is required. Thus it can be seen that in a great many problems, a digital machine can be used while an analog machine cannot. On the other hand there are a great many problems where an analog machine is much to be preferred (see Section III).

Accuracy

An automatic digital computer is surprisingly accurate. One of the earliest machines, the Harvard IBM Mark I, represented numbers of

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*See also Section III:4, p.000

23 decimal digits, and could be programmed to handle numbers of 46 decimal digits, in right and left halves. Many later machines, by double-precision programming, can easily handle numbers of 20 or more decimal digits. Eniac, another early machine, has been used to compute π, 3.14159265....., to 2000 decimal digits.

Accuracy to such a high degree is not often useful. But every now and then a computation depends for its success in determining a very small number that is the difference of two nearly equal very large numbers; then such accuracy is essential in order to obtain any answer at all. One machine, the IBM Electronic Selective Sequence Calculator, which operated for a few years starting in 1947 before being dismantled, calculated the motion of the moon with new and remarkable accuracy, locating the moon precisely in the heavens at six-hour intervals for four centuries.

Reliability

A good automatic digital computer may run for four or five hours without making an error. At 25 million calculating operations per hour, this means that the machine can perform over 100 million calculating operations with numbers without making a mistake. This degree of reliability has never previously been obtained in mathematical calculation, nor in any other operations by machines. Considering the large number of parts in an automatic digital computer, this degree of reliability is really phenomenal.

Speed

One of the great advantages of a large automatic digital computer is its speed of operation, over 10,000 representative calculation operations per second. Thus in ordinary arithmetical operations its advantage over human beings is in the neighborhood of 100,000 times faster. This is a direct consequence of the use of electronic principles, and is one of the foundations for the unprecedented powers of an automatic digital computer.

Memory

Another of the great advantages of an automatic digital computer is its lasting capacity to store a great amount of information, its enduring memory, together with automatic access. For example, the magnetic tapes which can be consulted at any one time by a Univac contain 86 million binary digits; these can remain stored for dozens of years or be erased at any time.

In effect, unlike a human being, the machine does not forget. Of course, there may be some exceptions; for example, some magnetic spots may not record because of a double failure, the combination of a poor section of magnetic tape and malfunctioning of detection circuits expressly inserted in the computer to forestall this contingency. Nevertheless, the proportion of information that a computer can remember will be far, far greater than the proportion a human being can remember.

Disadvantages

Unadaptability

Perhaps the prime disadvantage of an automatic digital computer from the viewpoint of many people in business and in certain special fields is its unadaptability to many kinds of information-handling problems. It will not tell a fisherman where in the sea to find the largest amount of fish (for lack of data). It has not yet told a weather man how to predict the weather any better (because of lack of formulas, high cost, and insufficient speed), although a good deal of effort is being devoted to developing automatic weather forecasting. It will not tell a mail order house how and what items to stock so that the largest sales will accrue (because of lack of data, insufficient formulas, and high cost). Here again, though, the principles for possible application are being carefully studied. It may be argued that inability to deal with such problems cannot logically be considered a disadvantage because the essence of data-handling devices is obviously the presence of data, and in such cases as just pointed out adequate data are not available. Unfortunately, the aura of infallibility that surrounds these devices as a result of colorful publicity has given the impression that they can solve any type of problem. A computer should not be blamed for being unable to handle all problems any more than a man should be blamed for failing to be a good wrestler if he has never claimed to be one.

Certain areas of information-handling are competently handled by human beings, and no automatic digital computer is yet near to being able to deal with them. One is the analysis and recognition of sounds, so that they are realized to be words and understood as such. It will be a long time before a machine can perform something as complicated as this in the form of information-handling. A similar exploit distant in the future is the capacity to take in sights and recognize them. Yet even here a beginning has been made, in the electronic reader developed by Intelligent Machine Research Corporation mentioned earlier. Human beings will still be needed as sales personnel because they can recognize the stock and answer customers' questions, a feat no machine is able to perform, although the vending machine has arrived. Likewise, bus drivers should have no immediate fear of being supplanted by automatic computers, although an automatic pilot (an analog machine) guides aircraft successfully.

Cost

Another big disadvantage of present automatic digital computers is their high cost: both initially and for upkeep. Since they do a great deal of work, the expense can be justified by those companies which have a great deal of information-handling to do. But smaller organizations will have to either send their computing work out to service bureaus, or else wait for lower-priced automatic computers to become available.

Not only the expense of acquiring and maintaining the machine, but also the expense of the staff and the expense of programming, must be borne. A user wants answers to problems, not necessarily a computer.

Another fair sized part of the expense of a computer is the cost of the power required to run it. From 25 to 100 kilowatts is the normal requirement for a large capacity automatic digital computer. Fortunately, the development of computer components requiring less power, particularly transistors, is likely to reduce the cost of computers considerably.

Fragility

The automatic digital computer is, at the present time, a rather fragile piece of apparatus, made up of a great many different parts. Under slight provocation it can get out of order. However, it should be remembered that it took about twenty-five years for the automobile to become a machine which only rarely needed repair while in use.

Balance Sheet

On balance, it is easy to see that an automatic digital computer may be a great advantage in a particular situation. But it is not something to be bought on an afternoon's shopping expedition!

II:8 A CHECKLIST OF CHARACTERISTICS OF AN AUTOMATIC DIGITAL COMPUTER

Having discussed the various functioning units of an automatic digital computer, its reliability, and its advantages and disadvantages, we can now turn to the question, "Suppose we have decided to obtain an automatic digital computer for some application—what are the characteristics we should look for?"

When considering an automatic computer for some application, one must be sure that it has all *essential* characteristics and as many *desirable* characteristics as possible. For this reason, a checklist of characteristics should be extremely helpful. Such a checklist is given in full below. But first we shall describe how it was constructed, what information it contains, and some things to be remembered when using it.

Construction of the Checklist

A great many characteristics of automatic digital computers may be observed. Manufacturers' descriptions of their computers usually contain reports on many features, particularly the more favorable and striking ones; those which are not wholly favorable are often omitted. Of course this is in accordance with the nature of businesses as well as human beings.

The present checklist is the result of a long attempt to assemble those characteristics which have at least some bearing on a practical application of a digital computer. It is likely, however, that the checklist is not exhaustive, and that some more characteristics may logically be included.

Classification of Characteristics

Because of the large number of characteristics that may be observed, it is desirable to compare and classify them. The main classification is according to the "logical department or subdivision" of the subject of an automatic digital computer for a practical application:

W, whole machine
M, memory
A, arithmetic unit
I, input unit
O, output unit
P, programming, control
R, reliability, maintenance
C, cost
S, supply

The letters designating these classes have been used also in numbering characteristics serially within each group.

Relative Importance

A characteristic may be classified in several grades of importance according to the extent to which it may fulfill the objectives of a practical application in a business. In the checklist, a grade of importance is given in the first column opposite each characteristic. The system of grades adopted is as follows:

1 – of basic importance
2 – of considerable importance
3 – moderately important
4 – desirable but not important
5 – of no particular importance

The application assumed is a business having several thousand employees, where a large amount of information is manipulated, most of a commercial nature, some of an engineering nature.

The relative importances shown here are, of course, not objective: that is, different people will very likely assign different grades of importance to the same characteristic. Also, for other types of practical applications besides the one we have assumed, different grades of importance may well apply. On the other hand, it should be relatively easy for someone preparing to use the checklist, to go through it altering the grades of importance to suit the particular application which he has in mind.

In judging the requirements of the assumed business, the whole group using or supervising the computer and responsible for issuing results has been kept in mind; and the degree of importance has been assessed to reflect their composite interests.

It may be wondered why a characteristic of Grade 5, "of no particular importance," should be included in the checklist. For example, a characteristic of Grade 5 is:

> Presence and amount of memory using: mercury tanks, magnetic tape, magnetic drums, electrostatic storage, magnetic cores, electronic tubes, relays, etc.

The point of view adopted in the construction of the checklist is that, for the purposes of a user, an automatic computer is essentially a black box with certain behavior. The user is interested in the behavior, and so it is of no particular importance to him what kind of hardware produces the behavior. Hence this characteristic is properly classified as Grade 5. Nevertheless, in thinking about a computer, understanding how it is operating, remembering the association of characteristics with each other, and estimating the cost of maintenance, it is a help to the user to know what kind of hardware is inside the black box, and in particular what kind of hardware fulfills the function of the computer memory. Hence this characteristic quoted above is properly included in the checklist (and could of course be expanded into a dozen or more characteristics, instead of being treated as a single one).

Discrimination

A characteristic may also be classified as "discriminating" or "nondiscriminating." A characteristic is discriminating if different automatic computers may have substantially different degrees of the characteristic. For example, "digital" is not discriminating because all computers that may be considered will be digital. In the checklist, D for "discriminating" or ND for "nondiscriminating" is given in the second column opposite each characteristic.

Performance

Another classification of the characteristics of computers is according to the extent to which they affect the performance of the machine. For example, "number of registers of rapid memory" directly affects the performance of the computer, but the "number of magnetic drums for the storage of information" may have no relation at all to performance. In other words, the larger the number of registers of rapid memory, the better the performance of the computer; but, from the number of magnetic drums (0, 1, 2, 3, 4, etc.) no conclusion can be drawn (without other information) about performance. In the checklist, in the third column opposite any characteristic, is given "P" for "affecting performance" and "NP" for "not affecting performance."

Use of the Checklist

The primary use of the checklist is to give a picture of almost all the significant properties of an automatic digital computer, and to assist the purchaser in making a selection from among a group of computers by rational means.

It is not to be expected that every one of these characteristics can be reported for every computer. However, at many stages in the examination of a computer, reference to this checklist is likely to be helpful.

CHECKLIST OF CHARACTERISTICS

Item	Description	(1) Impt.?	(2) Discr.?	(3) Perf.?
	W. Whole Machine			
W1.	Digital, or analog	1	ND	P
W2.	Degree of matching of the operating speeds and capacities of input, arithmetic unit, storage, output, etc. (i.e., degree of absence of bottlenecks in the flow of information into, through, and out of the machine; balanced design)	1	D	P
W3.	No. of characters in a regular machine word	2	D	P
W4.	No. of binary digits equivalent to one machine character (excluding checking)	2	D	P
W5.	No. of binary digits equivalent to a machine word	2	D	P
W6.	No. of machine words to a machine register (customarily, one)	5	ND	P
W7.	Extent to which the machine is parallel or serial	5	D	NP
W8.	Degree to which machine can operate with alphabetic characters, punctuation, etc.	1	D	P
W9.	No. of kinds of machine language (such as magnetized spots, punched holes, etc.) which machine or easily provided auxiliary equipment can handle	3	D	P
W10.	Operates internally in decimal or binary	1	D	P
W11.	Degree to which the number of units of equipment in the machine installation may be varied to suit requirements	2	D	P
W12.	Capacity of the machine installation to be expanded by adding on newly designed units of equipment (customary)	2	ND	P

Item	Description	(1) Impt.?	(2) Discr.?	(3) Perf.?
	M. Memory			
M1.	No. of equivalent binary digits that can be stored in a machine register	1	D	P
M2.	No. of registers of rapid memory (i.e., memory accessible automatically to the machine and rapidly)	1	D	P
M3.	Total rapid memory measured in thousands of binary digits	1	D	P
M4.	Permanence or volatility of rapid memory	3	D	P
M5.	No. of registers of slow memory (i.e., memory accessible automatically to the machine but not rapidly)	1	D	P
M6.	Total slow memory measured in millions of binary digits	1	D	P
M7.	Permanence or volatility of slow memory (customarily permanent)	1	ND	P
M8.	Total memory measured in millions of binary digits	1	D	P
M9.	Access time to a specified register of rapid memory	1	D	P
M10.	Access time to a specified register of slow memory	2	D	P
M11.	Time to search for and find the register of rapid memory containing specified information	2	D	P
M12.	Time to search for and find the register of slow memory containing specified information	2	D	P
M13.	Ability to store instructions or numbers interchangeably in any part of the memory (customary)	1	ND	P
M14.	Presence and amount of memory using: mercury tanks, magnetic tape, magnetic drums, electrostatic storage, magnetic cores, electronic tubes, relays	5	D	NP
M15.	Adaptability of machine to external storage on: punched cards, punched paper tape, storage tape	2	D	P

Item	Description	(1) Impt.?	(2) Discr.?	(3) Perf.?
	A. Arithmetic Unit			
A1.	Capable of performing all kinds of arithmetical operations (customary)	1	ND	P
A2.	Capable of performing all logical operations occurring in mathematical work (including comparing, selecting, reference, etc.)	1	D	P
A3.	Capable of performing all kinds of logical operations (including sorting, matching, merging, collating, etc.)	1	D	P
A4.	No. of complete additions (or subtractions) per second	1	D	P
A5.	No. of complete multiplications per second	1	D	P
A6.	No. of complete divisions per second	2	D	P
A7.	Time for making a logical comparison	2	D	P
A8.	Time for making a transfer of a machine word from one register to another	2	D	P
A9.	No. of representative calculating operations per second (determined generally as nine additions and one multiplication divided by ten)	1	D	P
	P. Programming			
P1.	Capable of an unlimited sequence of operations (customary)	1	ND	P
P2.	Able to solve very many different kinds of problems	1	D	P
P3.	Average time for preparing a program for a new problem for the machine	1	D	P
P4.	Average time for verifying a new program for the machine	2	D	P
P5.	Capacity of the machine to determine and report the reasons for the failure of a new program to run	1	D	P
P6.	Able to select a subprogram depending on indications arising in the problem (customary)	1	ND	P
P7.	Able to compute a program for itself (customary)	2	ND	P

Item	Description	(1) Impt.?	(2) Discr.?	(3) Perf.?
P8.	Library of programs available from manufacturer	2	D	P
P9.	Able to compile a program for itself by selecting and assembling programs from the library	2	D	P
P10.	Able to calculate to double precision (customary)	2	ND	P
P11.	Able to use either floating point or fixed (customary)	2	ND	P
P12.	Able to convert automatically by program or special device from binary to decimal and vice versa (customary)	3	ND	P
P13.	Able to translate from one system of coding for instructions to another system of coding for instructions	4	D	P
P14.	No. of different orders in instruction code	5	D	P
P15.	No. of addresses in instruction code	5	D	P
P16.	Versatility of different orders in instruction code	2	D	P
P17.	Room for expansion of instruction code	1	D	P
	I. Input			
I1.	No. of words machine can take in in one second	1	D	P
I2.	Equivalent no. of binary digits the machine can take in per second	1	D	P
I3.	Average time for preparing 100 words for input into the machine	2	D	P
I4.	Average time for verifying completely 100 words put into the machine	2	D	P
I5.	Average time for changing the machine from one program to another (customarily small in recent computers)	1	ND	P
I6.	Capacity of the machine to accept numbers of a wide range of magnitude (the opposite extreme of the characteristic is "machine requires all numbers to be scaled between 1 and −1")	1	D	P

Item	Description	(1) Impt.?	(2) Discr.?	(3) Perf.?
I7.	Capacity of the machine to accept numbers from one or more input mechanisms at the same time that the arithmetic unit is calculating	1	D	P
	O. Output			
O1.	No. of words machine can put out in one second into external memory or high-speed control signals	1	D	P
O2.	Equivalent no. of binary digits machine can put out in one second into external memory or high-speed control signals	1	D	P
O3.	No. of words that auxiliary equipment can transfer in one minute from machine external memory into: punched cards, punched paper tape, electric typewriter printing, line-at-a-time tabulator printing, oscilloscope presentation, graphic chart presentation	3	D	NP
O4.	No. of binary digits per minute equivalent to Item O3.	3	D	NP
O5.	Capacity of the machine to insert numbers into one or more output mechanisms at the same time that the arithmetic unit is calculating	1	D	P
	R. Reliability			
R1.	Operating ratio, if any (i.e., ratio of good operating time to total time one tries to operate)	1	D	P
R2.	Average operating ratio at manufacturer after trial period if any	2	D	P
R3.	Average operating ratio at customer's after trial period if any	2	D	P
R4.	Degree of automatic checking in the machine	1	D	P
R5.	Extent of reliance on programmed checking	1	D	P
R6.	Extent to which additional circuits and devices have been built into the machine to detect approaching failures before they occur (i.e., marginal checking facilities)	2	D	P

Item	Description	(1) Impt.?	(2) Discr.?	(3) Perf.?
R7.	Expected usual time to locate and repair failures (i.e., the statistical mode of down-time)	2	D	P
R8.	Ease of access to parts	2	D	P
R9.	Ease of diganosis of failing equipment	2	D	P
R10.	Ease of repair or replacement of failing equipment	2	D	P
R11.	Average time that machine can operate before intervention by human attendant is required	4	D	P
R12.	Years of customer experience with machines of the type, if completed	1	D	NP
R13.	Degree to which machine has passed Government acceptance tests, if any	1	D	P
R14.	No. of parts	3	D	NP
R15.	Degree to which parts are standard	3	D	NP
R16.	No. of kinds of parts	3	D	NP
R17.	No. of kinds of main components in machine	3	D	NP
R18.	No. of kinds of plug-in units in the machine	3	D	NP

S. Supply

Item	Description	(1) Impt.?	(2) Discr.?	(3) Perf.?
S1.	Estimated months from date of decision to date of operation of installed machine	1	D	NP
S2.	Estimated months from date of decision to date of acceptance of order by supplier	2	D	NP
S3.	Estimated months from date of order to delivery of machine	2	D	NP
S4.	Estimated months from delivery of machine to successful operation of installed machine	2	D	NP
S5.	Produced on assembly line, or on special order	2	D	P
S6.	Order willingly taken or only under pressure	1	D	NP
S7.	Availability of adequate supply of spare parts at the site of installation	2	D	P

Item	Description	(1) Impt.?	(2) Discr.?	(3) Perf.?
	C. Cost			
C1.	Purchase price	1	D	NP
C2.	Annual rental, assuming one shift	1	D	NP
C3.	Annual rental, assuming two shifts	2	D	NP
C4.	Annual rental, assuming three shifts	2	D	NP
C5.	Amortized annual expense of computing facility	1	D	NP
C6.	Amount of power required	2	D	NP
C7.	Air-conditioning required	2	D	NP
C8.	Floor space required	2	D	NP
C9.	Organization responsible for maintenance of the machine	2	D	NP
C10.	No. of operators required	2	D	NP
C11.	No. of engineers and maintenance men required	2	D	NP
C12.	No. of mathematicians and programmers required	2	D	NP
C13.	No. of card-punch or tape-punch girls required	2	D	NP
C14.	Size of staff required	1	D	NP
C15.	Availability of machine on a flexible basis, either sale or rent or other arrangements	2	D	NP

SECTION III

AUTOMATIC ANALOG COMPUTING MACHINES

III:1 THE ANALOG PRINCIPLE AND ITS USE

Analog computers, as the name is intended to imply, compute by means of setups that are analogs of the problems to be solved. A problem to be solved may be one in kinetics, such as the prediction of the future position of a target aircraft, or one in thermodynamics, such as the flow pattern of heat in an engine part, or one in almost any field of technology with formulas capable of mechanized representation. The analog may be set up by representing the variables of the problem as mechanical motions. An example is the representation of a target aircraft by a small button which is moved about so as to mimic the motions of the target. When the target moves a matter of miles the button moves only a few inches. The motion of the analog button is thus a replica of the target's, reduced by a large factor to give a small scale convenient for mechanical representation. Another way of setting up an analog is to represent the problem variables by electrical quantities. For example, the position coordinates of the target aircraft can be denoted by voltages which change as the position coordinates change with the target's motion. There is a continuous one-to-one correspondence between each coordinate value and its representative voltage—so many miles, so many volts.

Analog representations are in many forms. They may be mechanical or electrical as cited above, or they may be electronic, photometric, hydraulic, pneumatic, or other, or combinations of these. The quantities represented may be any of those which enter into the problem to be solved, such as distance, speed, acceleration, voltage, current, temperature, light intensity, fluid pressure, and many others.

In general, it is possible to use any one or many of a large variety of effects to serve as analogs of almost any others, providing they are used consistently. For example, a mechanical system may be analoged by an electrical or optical system, or vice versa. In some cases a large mechanical system may be analoged by a small mechanical equivalent—a model. The same thing may be done in the electrical or other fields. In such representations, we may denote the analog as one of similitude, to distinguish it from those in which the correspondence is more abstract.

Analog computers can be very simple devices or they can be quite complex. The simpler ones are very numerous. In fact, we encounter many simple analog computers every day, although we may not have considered them as such. These devices, however, fulfill a broad definition of analog computers and may be considered as such. The electric, gas, and water meters which determine our monthly bills for these commodities are analog computers in the broader sense. Another example is the speedometer of an automobile together with its mileage counter (called *odometer*). Let us consider this in some detail.

A speedometer-odometer incorporates all the essential elements of a computer as we shall see later. It is principally analog, but typically includes digital features as well. Its input is a rotation, derived from the car's main drive shaft with the help of a flexible shaft. Its outputs are visual indications of the distance the car has traveled and its speed.

The odometer has several dials. The right end dial indicates in units of 1/10 mile. The next dial to the left reads in miles, the following one in tens of miles, and so on. Now the figures on the 1/10-mile dial move only a fraction of an inch while the car is traveling a tenth of a mile (528 feet). This is so because of a gear reduction between the input rotation and the dial. The gear reduction is an analog *multiplication* which reduces the original 528 feet of car travel to the fraction of an inch which the dial moves.

Each time the 1/10-mile dial completes a full turn, meaning that the car has moved a mile, the turn of the 1/10-mile dial is counted by the 1-mile dial. This counting is digital because the 1-mile dial (aside from an instant of change) always rests precisely on a digit, i.e., it reads, say, 5 or 6, but not any intermediate value (excepting the brief moment of change). This effect is accomplished by means of an intermittent gear, and it is repeated for the 10-mile, 100-mile, and the remaining odometer dials. Thus, these dials count or *add* the turns of the 1/10-mile dial.

Turning our attention to the speedometer portion of the instrument, we note that the input rotation is used to operate this part as well.

Other gearing *multiplies* the rotation so that its speed is an optimum to actuate a magnetic and spring action which positions the speedometer pointer. This effect measures the input rotation speed, and hence the speed of the car, and furnishes a visual output to the driver. The measuring of the varying rate of travel of the car is analog *differentiation,* as the speed is the mathematical derivative of the travel (with respect to time).

The common automobile speedometer-odometer has thus furnished an example of an analog computer which includes multiplication, addition, and differentiation. The multiplication was done by gearing. Gearing also performed the addition, with an intermittent feature to produce a digital result. Differentiation was effected by a magnetic and spring action. None of these processes is difficult to understand by itself, and so it should be with the more intricate computers when we break them down into their elementary components.

The everyday computers so far mentioned are quite special purpose; they can solve only a definite problem which has been built into them once and for all. Other computers are sometimes capable of handling a variety of problems.

III:2 THE ESSENTIAL ELEMENTS

The analog computer has seven essential elements, but the number may be more or less depending upon the grouping chosen. The degree to which each element is featured in a computer will vary, but it must be present if only in vestigial form. The same elements are required in digital computers although in different form and with different emphasis. In fact, a human computer must supply these elements, either in himself or in the tools of his trade such as his pencil and paper.

The list of essential elements according to our selected grouping is:

1 – Quantity representation
2 – External links
3 – Storage
4 – Operations
5 – Transfer
6 – Control
7 – Power supply

As stated above, this list can be regrouped to a larger or smaller number. For example, "external links" (input-output) can be considered merely a specialized form of "transfer," or "control" could be listed under "operations," thereby reducing the number of elements listed separately. On the other hand, "input" and "output" might be considered as separate elements, and similarly for other items in the chosen list. In short, the grouping is arbitrary and the above list is submitted as a useful version.

Quantity Representations

Quantity representations may take many forms. They may be mechanical lengths or angles, electrical or electronic voltages or currents, or they may lie in other fields such as optics, hydraulics, pneumatics, etc. The same quantity may have several representations in a given computer. For example, it may be the displacement of a pin in one part of the computer and the rotation of a shaft in another part. In all cases there is one-to-one correspondence between the physical representation to a convenient scale and the abstract quantity in suitable units.

External Links

External links between the computer and its environment are necessary if it is to perform any useful function. There must be means for instructing it as to the program it is to follow and for furnishing it the problem data. There must also be means by which the computer can deliver its results. The means for program instruction, and even many of the problem data, may be permanently built into the computer. In this case it is a special purpose computer. On the other hand, a considerable portion of the program and most of the data may be subject to change; then the computer tends towards being multipurpose. In any event, there must be at least some input-output facility.

Storage

The computer must have means for remembering the orders and data given to it until it has complied with the orders and is through with the data. Means are also needed for storing any intermediate orders or data until used and for holding results until they have been delivered via output. Of course, any particular information may be retained by the computer, depending upon its construction, until the memory has been cleared by some affirmative action. A particular case will be tabular-type data that are of general applicability, such as interpolation coefficients.

As already pointed out, many or all of the orders, and some or most of the data, may be built into the computer, so that they do not have to be supplied at the beginning of a problem. If so, we may then consider that those features of the machine which hold such information are a part of the storage. However, there must be at least some storage which is capable of change or the machine would be not a computer but a static device.

Storage is another point of difference between analog and digital computers. In digital computers, the storage is prominently featured and tends to be very large, while in analog ones it may be so distributed and so varied as not to be readily recognized as a separate entity.

The Operations Element

The operations element is the heart of the computer; the other elements are merely facilities to make possible its functioning. It is therefore this primary element which tends to fix the character of the computer.

The operations element will usually comprise a number of components for performing simple or composite mathematical or quasi-mathematical operations on quantity representations or orders (which may be in the form of quantity representations). An operation may be a simple one such as addition or subtraction, multiplication or division, integration or differentiation, or it may be a composite one such as vector addition or the formation of an arbitrary function. The component which performs an operation may be specially devised to accomplish the analog of an abstract effect, such as the disc and wheel arranged to integrate (p. 105). Again, it may be a unit which naturally yields the physical effect desired, such as an electrical impedance arranged to develop a wanted phase angle (p. 110).

One very important class of operations is conversions. These may be needed to transform quantity representations from one form to another, from one scale to another, from one level to another, or from one code to another. Conversions may be needed for both orders and data. Simple examples of conversions are those for converting a length into an angle by rack and pinion (p. 94), and for converting an angle into a voltage by rotary potentiometer (p.94).

Another type of operation deserves more consideration in analog computers than it has had so far. This operation would effect a branch order, as it is called in the digital field where it is essential to general purpose operation. That is to say, a branch operation would virtually permit the analog computer to determine the course of a problem by the values generated during its solution.

The Transfer Element

The transfer element of a computer provides the channels and switching by which orders and data are transferred between units of the computer. It may comprise shafts, gearing, and clutches in a mechanical device or electrical busses, relays, and diodes in an electrical device. Combinations, of course, will be common. Some transfer units may be extremely simple, such as a link or a wire. If any transfer paths are permanently connected, then the computer is to that extent inflexible. If, on the other hand, many of the channels are controlable, the computer will tend towards flexibility and multipurpose applications.

The Control Element

The control element, of course, sees that the orders are executed. It may include means for monitoring the computer operations so that faulty operations will be prevented, or at least minimized. The monitoring means may also report to an attendant the progress of the solution and any conditions requiring his intervention. A particular form of monitoring is mathematical checking, a prominent consideration in digital machines. Checks of various sorts may be practicable in analog machines as well.

The control element may be vestigial in simple computers. That is to say, the control may be fixed once and for all by the structure of the device. Again, this means a single purpose computer. However, no matter how simple the machine, some control is essential.

Power Supply

The final element, power supply, requires little comment at this point. It may be one or more electric motors or an extensive set of voltage sources. It may even be merely a knob or a crank for hand operation. The need for, and character of, the power supply will be obvious.

In summary, it may be said that each of the foregoing seven elements is essential to any computer. The elaborateness of any one will depend upon the particular computer. In some computers, they may be explicitly featured, while in others they will be implicit in the structure. An element may be largely concentrated in particular parts of the computer, or it may be dispersed throughout it. In any event it must be present.

The Human Computer

There is, of course, a close parallel between the human computer and a computing machine, analog or digital, for they can achieve the same results in substantially the same way. The human computer faced with a problem requiring numerical solution will utilize the same essential elements as a computing machine. He must find these elements in himself or in the simple tools of his trade such as paper and pencil, book of tables and formulas, desk calculator, slide rule, ruler and compass, and so forth.

The human computer may work with digital or analog quantity representations or a combination of them. With digital representations he will usually employ the decimal notation, while with analog representations he will be making geometric constructions, graphs, and so forth. External links will be principally by written memoranda and verbal communications.

The human computer's active storage will be mostly his memory and the marks he makes on paper. Extended storage will be available in printed tables, nomograms, etc. His most frequent digital operations will be addition-subtraction and multiplication-division. He may program these so as to effect root extraction, integration, and so forth. Similarly, his analog operations will usually be simple ones, such as vector plotting. These may be programmed to accomplish more sophisticated results, such as an application of the Nyquist criterion (servo theory).

The transfer element will be mostly mental or manual but may reside in the implements used. For example, transfers will occur in the desk calculator, if used, and a straight-edge may be needed to shift quantities between graphic scales. The control element will reside mostly in the human computer's mind but will be supplemented by such stored routines as books of formulas. Power supply will obviously be almost entirely manual.

The foregoing considerations indicate that human and machine computers depend upon the same essential elements although their form and emphasis may differ. Each must be able to represent, store, and transfer quantities and instructions. Each must have links with its environment, must be able to perform computational and logical operations, and must be capable of following an appropriate program. Both require some form of power.

III:3 A SIMPLE COMPUTER

The foregoing discussion, which considers computers in general, may become clearer if we consider an actual example of a computer. A simple example will be more readily explained and understood, but it should not be so simple as to fail to exhibit at least several of the concepts discussed above. Such an example is depicted schematically in Figure 2, in which details which are not required for the description have been omitted. In the following paragraphs we shall indicate a possible practical application for this computer, and give a detailed description of its construction, operation, and theory. We shall also explain how each of the seven essential computer elements is incorporated, and again indicate the meaning of the name "analog."

Possible Application

The computer of Figure 2 is mechanical. While it is not known to have been so used, it could be the computer portion of a recording gas flow meter. If so, then x might represent the pressure differential across the meter orifice (say in lbs/sq in.), y might represent the downstream density (say in lbs/cu ft), and z might represent the rate of gas flow (say in lbs/sec). Certain constant factors which enter into the problem could be taken care of in the calibration of the scales or by means of a simple mechanism which is not shown.

The Mechanism Described

The computer operates essentially in a plane and the page on which the figure is printed may be considered as a base board. Parts

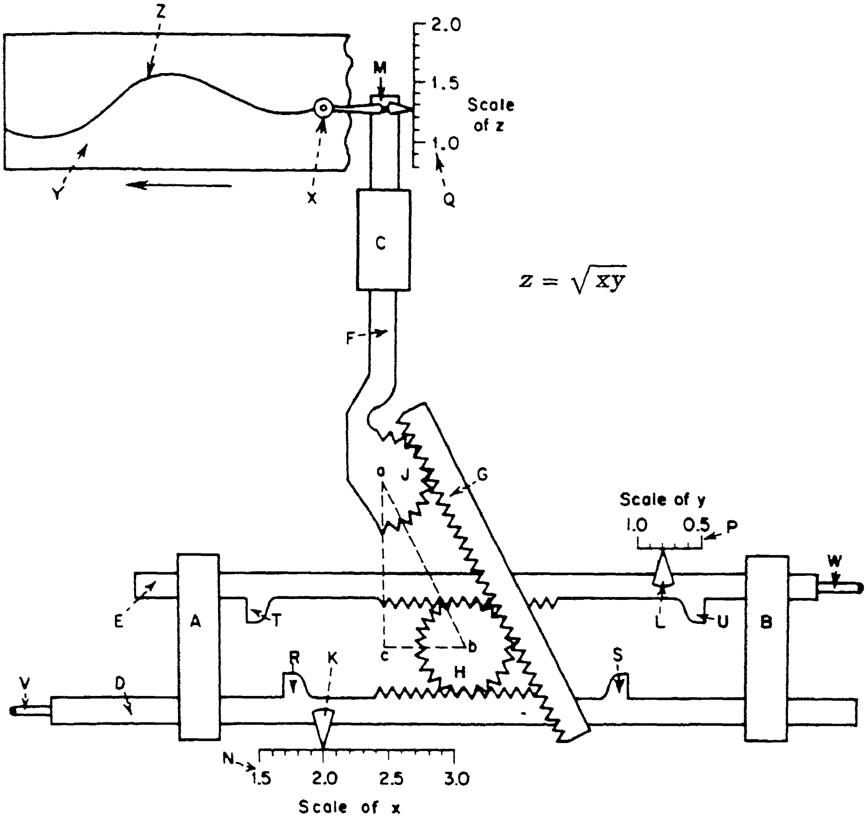


Figure 2. Simple computer.

A and B are fixed blocks through which square rods D and E may slide, right and left. The extent of sliding permitted is limited by stops R, S, T, and U. Portions of rods D and E are toothed racks, and between these racks is spur gear H which rolls right or left as the rods are moved. The gear H also engages the rack G which in turn engages the half-gear J. The half-gear J, which is the same size as the gear H, is carried on the end of a square rod F. This rod can slide up and down in the fixed guide block C. When the gear H moves, either in translation (right or left) or in rotation (clockwise or counterclockwise) the rack G transmits the motion through the half-gear J to the rod F. Rod F is consequently moved (up or down). The amount by which rod F moves as a consequence of the motion of gear H depends upon the geometry existing at the moment, i.e., upon the size and shape of the right triangle abc, shown in broken lines. The exact way in which the motion of rod F depends upon the motion of gear H, and hence upon the motions of rods D and E, will be explained below. However, it is worthwhile noting here that gear H can translate (right or left) without rotating if the two rods D and E move right or left at the same time and in the *same direction* by the same amounts. Gear H can also rotate (clockwise or counterclockwise) without translating if rods D and E move at the same time in *opposite directions* by the same amounts. In either case, i.e., simple translation or simple rotation, the motion of gear H will require a motion of rod F by means of rack G and half-gear J. Of course, in general, rods D and E will move independently and gear H will roll, i.e., both translate and rotate.

Rods D, E, and F carry pointers K, L, and M which can be read against scales N, P, and Q on the base board. These scales indicate the positions of the rods. Rod F also carries a pen X which draws a curve Z on paper chart Y. This chart is moved uniformly to the left by a clock motor. Curve Z is thus a time record of the position of pen X.

As indicated on the figure, the function which the computer mechanizes is $z = \sqrt{xy}$. The quantities x, y, z are represented by the positions of the rods D, E, F. For example, when rod D is at the extreme left (stop R against block A), the value of x is 1.5. As rod D moves to the right, x increases until stop S reaches block B, when x is 3.0. Of course, the scales and stops are assigned arbitrarily, with a view to requirements and to the limitations of the mechanism, and those shown are merely illustrative.

Operation of the Mechanism

First, consider rod E stationary. As rod D moves to the right, gear H is rolled between the moving rack on rod D and the stationary rack on rod E. Instantaneously, the pitch point of gear H in contact with rack D moves at the same rate as rack D while the opposite point of gear H which is in contact with rack E remains stationary. This is so because rack E is supposed stationary. As a result, the point b at the center of gear H moves to the right at *half* the rate at which rack D is moving. The reason for this is that the center point of gear H is *half* way between two points on the gear, one of the points moving and the other not moving. Of course, the particular points on gear H are continuously changing, but point b is always moving at *half* the rate of the moving rack.

Second, consider rod D stationary and rod E moving to the left. In this case point b moves to the left at half the rate of the moving rack. This is similar to the previous case, only now the racks are interchanged and the motion is to the left. Finally, consider both rods D and E as moving. Now both the first and second cases just discussed occur together and the point b moves so as to satisfy both of them. In other words, as x and y change, point b moves according to the change in $\frac{1}{2}x$ minus $\frac{1}{2}y$ or $\frac{1}{2}(x-y)$. However, the device was originally assembled so that the position of point b at the start was such that the length bc represented $\frac{1}{2}(x-y)$ for the values of x and y at assembly. This being so, the changing length bc will always represent the changing value of $\frac{1}{2}(x-y)$.

Again suppose rod E at rest and rod D moving to the right. As gear H rolls it not only translates but also rotates counterclockwise. This rotation of gear H forces rack G towards half-gear J; thereby the distance ab is increased by *half* the amount that rack D translates. On the other hand, if rack D is at rest and rack E moves to the left, gear H is still rotated counterclockwise. Again the length ab is increased by *half* the amount that rack E translates. When both racks D and E move, the distance ab is changed by half the sum of their motions. The factor *half* comes from essentially the same phenomenon as before. Also as before, the device is so assembled that initially, and hence thereafter, length ab represents $\frac{1}{2}(x + y)$.

It may be noted that the function of the nonrotating half-gear J is to keep rack G parallel to line ab and to permit rack G to push or pull rod F. The equality of pitch radii of gear H and half-gear J prevents a parallax error which would otherwise be introduced as the angle abc changes.

Theory of the Mechanism

It has now been shown that in the right triangle abc, length ab represents $\frac{1}{2}(x + y)$ and length bc represents $\frac{1}{2}(x - y)$. Therefore, length ac represents $\sqrt{xy}$ by the well-known Pythagorean theorem. Index M and pen X (which were correctly positioned on initial assembly) will always indicate $z = \sqrt{xy}$ as x and y are varied within their prescribed limits. If x linearly represents the pressure differential in our flow meter, and y linearly represents the downstream density, then z will linearly represent the mass flow rate (hydrodynamic theory). That is to say, all three scales are linear and without theoretical approximation insofar as the product-square root function is concerned.

If the computer is used as part of a recording flow meter, the rod D would be moved by a pressure differential pick-up, say an opposed pair of bellows, through the link-rod V. The rod D would be positioned through link-rod W by a density pick-up, perhaps some form of fixed-volume weighing device. Alternatively if downstream temperature is constant (or compensated), a pressure-actuated bellows could be used.

The index M would indicate the instantaneous flow rate and the curve Z would present a running record of it. The area under curve Z would be proportional to the total mass flow during the time considered.

How the Essential Elements are Incorporated

Having described the construction, operation, and theory of the computer, it is now in order to consider how each of the essential elements is represented. It will be noted that the ascribing of an element to a particular part or parts is somewhat arbitrary and may depend upon the points of interest at the time. For example, when several units simultaneously represent the same quantity, it may be a matter of choice as to which unit or units are considered to be the storage for it.

The *quantities* x, y, z are obviously *represented* by the linear positions of the rods D, E, F. They also occur, modified and in combination, in the linear and angular positions of gear H and in the linear extension of rack G.

The *external links* are: input, link rods V and W for x and y; output index M (with scale Q), and pen X (with printed scale on paper Y).

The *storage* of quantities x, y, z may be identified with the rods D, E, F. We may also regard gear H as a storage for $\frac{1}{2}(x - y)$ in the length bc and rack G as a storage for $\frac{1}{2}(x + y)$ in the length of ab.

The *operation* of conversion between linear displacement and angular rotation is performed by the rack and pinion effects. Gear H both adds and subtracts. The operation of producing the square root of the product of x and y is accomplished by the cooperation of racks D, E, G and gears H, J with the aid of rods D, E, F and blocks A, B, C in the configuration shown. This operation could, of course, be performed in many other ways. In particular, the forming of the product and the extraction of the root could be done by separate mechanisms. The operations of indicating are performed by indices K, L, M against scales N, P, Q. The operation of recording two-dimensionally is achieved by means of the pen X and the clock-driven paper Y. Other operations could, of course, be added. For example, rod F could control a time-based integrating mechanism. This mechanism would then yield (for our flow meter) the total mass flow for the time of integration.

The *transfer* links are rods D, E, F, racks D, E, G, and gears H, J. Note that most of these have also been considered as storage.

The *control* of the computer is built in; it is a single purpose device. Conceivably it could be operated otherwise, say to determine x when y and z are given; however, it is not well adapted to such use in the form shown. The only monitoring provided is that the indices K, L and the scales N, P permit visual verification of the input values x, y. The only automatic check is that the stops R, S, T, U prevent x, y from exceeding their prescribed ranges.

Power is supplied by the input means and the clock motor; no servo power is required.

It should be noted that in the computer, when applied to a flow meter, the hydrodynamic law of gas flow is analoged by a geometrical arrangement utilizing the relations among the sides of a right triangle. This points up why such computers are called "analog."

III:4 ANALOG AND DIGITAL COMPUTERS COMPARED

Similarities and Differences

The basic similarity between analog and digital computers is that they both incorporate the same essential elements. Their basic difference is that the analog computer uses continuous quantity representations while the digital computer deals in quantity representations which are discrete. Examples of continuous quantity representations have been mentioned previously; others will be described. Discussion and examples of discrete quantity representations are given in other chapters of this book. Because many computers have both analog and digital features, examples of both kinds of quantity representation may be found in a particular machine.

Continuous quantity representations are subject to the limitations of physical measurements. They are seldom accurate to better than one part in 10^4; in fact the usual limit is 10^3 or even 10^2. Consequently, analog computation to an accuracy of better than 1/10 per cent requires exceptional effort either in physical realization or in mathematical artifice (see Section III:7) or in both. On the other hand,discrete quantity representations are not so limited and ranges of 10^{12} or more are not uncommon.

Digital quantity representations are essentially one-dimensional, i.e., they are an ordered set of numbers which can be placed in one-to-one correspondence with a finite set of the natural integers. Analog quantity representations, however, may have two or more dimensions intrinsically. For instance, a vector may be three dimensional or an alternating current may be used two-dimensionally. Of course, either digital or one-dimensional analog quantity representations can be programmed to deal with multidimensional computations. When this is done the real and imaginary parts of a complex number are carried in associated storage units.

The external links for both categories of computers serve the same basic requirement of affording communication between the computer and the outside. Analog input is in the form of such continuous variables as shaft rotations and voltages. On the other hand, digital input is in such discrete forms as voltage pulses, the presence or absence of a perforation in a card or tape, or the depressing of a digit key. The comparison is similar for output. Analog input-output tends to be multichannel, whereas digital input-output in present-day machines is usually essentially serial. However, real time requirements will tend to change the digital picture.

Optimum utilization of both the analog and digital methods in combination calls for devices for converting from the one to the other. Speed is often a predominant consideration. For example, analog input data may be digitized and processed by a digital computer, and the results converted to analog form for process control or graphic display. All this may be done in real time.

In active storage, as in quantity representation, there is a wide divergence between the two computer categories. Digital storage tends to be concentrated in space, uniform in basic character, and (in the larger computers) interchangeably available to data or instructions. Its permanence is at least intended to be controllable. Common examples are: card and tape perforations; digit wheel positions; relay configurations; magnetic tape and core polarization; circulating pulse trains; cathode ray tube screen polarization arrays; and so forth. On the contrary, analog storage tends to be dispersed about the machine, diverse in character, and rarely interchangeably available for data and instructions. It is often either quite permanent, such as a cam or a fixed voltage divider, or quite transitory, such as the instantaneous position of a continuously rotating shaft or the instantaneous charge of a capacitor.

Analog and digital computers are also markedly different in their performance of mathematical and logical operations; however, they must obviously provide for the same or equivalent operations if they are to secure comparable results by essentially the same methods. Controlled arithmetic is the foundation for all digital mathematical operations. Contrariwise analog mathematical operations are performed by a large variety of single purpose units such as adders, multipliers, integrators, vector resolvers, etc. In other words, digital procedures are built upon the simplicities of arithmetic, the sophistication being supplied by the built-in or programmed routines which apply the simple arithmetic. On the other hand, analog procedures tend to employ devices which directly perform the more advanced operations. For example, a digital integration may use only addition to apply Simpson's rule, while an analog integration may be performed by a disc-and-wheel integrator.

In effecting internal transfers of instructions and data, digital machines will usually have very few channels which are mostly operated serially. This is so because of the large amount and considerable complexity of the switching necessary for general access. Analog machines, on the contrary, usually have a multiplicity of channels, most of them operating concurrently. Their switching requirements tend to be limited to initial setup and their channels are usually quite simple.

Both analog and digital computers must have control elements.

The program of an analog machine will be built-in to a considerable extent, owing principally to its limited numbers of single purpose units. For example, a mechanical differential analyzer will have a relatively small number of integrators and these can perform only integration or closely related operations. The programs of some digital machines, on the other hand, can be extremely flexible, ranging over almost all applied mathematics. This flexibility arises primarily from the fact that the most sophisticated digital computations can be resolved into sequences of simple arithmetical and logical operations. It is also promoted by the facility with which instructions and data can be processed interchangeably as regards storage, transfer, etc., and by the readiness with which branch orders can be used.

Power supply requirements are more a function of machine size than of machine category. However, it is notable that many analog devices have very modest needs. The electronic digital machines of large capacity presently require large amounts of power, first to heat their tube filaments and then to remove that heat. This situation will change, however, upon the widespread use of transistors and other components which can operate on minute fractions of the power which tubes require.

Advantages and Disadvantages

The paramount advantages of the digital category are its great flexibility and almost unlimited accuracy. Its leading disadvantages are its costliness, complexity, and fallibility, especially in the larger versions. These matters are, of course, subject to varying emphasis in different machines and for different applications. Conversely, the outstanding advantages of the analog category are liable to be relative cheapness, simplicity, and reliability. Its principal liabilities are its comparative inflexibility, and its very limited accuracy. However, for particular applications, analog computers which have been designed with ingenuity can often be surprisingly cheap, small, light, reliable, or rugged, or combine several of these qualities. Also, for particular applications, the flexibility of digital computers can be exploited by having them serve several functions on a time-sharing basis, thereby reducing their disadvantages in some respects while utilizing their advantages in others.

Operating speed is likely to be of great importance in real time applications and is seldom of no importance. Either category of computer may have the advantage, depending upon the particular problem and the type of computer (mechanical, electronic, or other).. However, the advantage between computers of the same type, say both electronic, is very apt to lie with the analog machine. While some electronic digital machines can run at a rate of several thousand complete operations per second, several hundred such operations may be required for a single solution point, and the problem may require a dense set of points. The analog machine, meanwhile, may be generating a continuum of solutions, thanks largely to its multiple concurrent transfer channels and its tailored-for-the-job operation units.

To consider advantages and disadvantages in relation to the essential elements, we note first that quantity representation in digital form has the tremendous advantage of virtually unlimited resolution. That in analog form has the advantage that the great majority of physical measurements are in the same form so that processing for machine use is apt to be quite simple. On the other hand, business, statistical, and similar data are likely to originate in digital form. These points also apply when we consider external links. Devices for digitizing analog data, for input to digital machines or as output from analog machines, and their counterparts for converting digital data to analog form, for input to analog machines or as output from digital machines, are currently undergoing considerable development, particularly as regards speed and accuracy. Such devices may be needed, for instance, when the output of a digital machine is to be displayed graphically or used as a process control.

Advantages of digital storage are its availability for instructions or data interchangeably and the ease and speed with which it can be modified in whole or in part. Its principal disadvantages, at least in certain forms, are the complexity of the access means and its vulnerability to operating troubles. Typical of such troubles is a power failure erasing a volatile memory. Analog storage is apt to be simple and reliable, but it may be very slow to reset. For instance, a screw must make many turns to reposition a traveling nut.

Digital operations are separately very simple and hence highly versatile. However, a great many simple digital operations have to be combined in a complex routine to achieve a higher level result which an elementary analog device can produce. Moreover, digital operations are usually executed serially, which is a distinct disadvantage from the standpoint of overall operating speed. Analog operations have the advantage, when applicable, of multidimensional action, which tends to increase overall operating speed. However, it has so far been impractical to construct an analog machine with even a fraction of the generality of the larger digital machines.

Analog transfer means are usually quite simple, say a rod or a pair of hook-up wires. Sometimes they may be more complex as with multispeed synchro-servo transmission. The switching is usually quite limited, especially as to controllability. The simplicity is an advantage but the inflexibility is not. Another advantage is multichannel operation which, although present from functional necessity, contributes vastly to overall operating speed. Digital transfer means tend to suffer the disadvantages of complexity and its resultant limitation on number of channels.

Digital control has the advantage of tremendous flexibility offset by the disadvantages of length and complexity. The need for, and the supplying of, close monitoring and checking are also drawbacks. On the other hand, analog control is usually quite simple and reliable but very limited.

III:5 EXAMPLES OF ANALOG COMPUTER UNITS

We shall now give some examples of the units used in computers, using our list of essential elements as an outline. The examples presented are only a small portion of the units which have been used, let alone others which could be used but have not been applied as yet. However, they should suffice to illustrate the nature of the field.

Quantity Representation

Computer units transfer, store, and operate upon numerical and logical quantities. These quantities are represented by physical entities which for analog numbers are such things as mechanical length and angle, electrical voltage, current, charge and impedance, pneumatic or hydraulic pressure and fluid mass, and so forth. The logical quantities are such things as the alternative states of a clutch which is engaged or disengaged, a relay which is operated or not operated, a route valve which is open or closed, and so on. The use of a number of such physical quantity representations has already been discussed; further examples will be given in this and the next chapter.

External Links

The means by which a computer communicates with its environment are usually specialized kinds of transfer units. They are characterized by the need for accepting or delivering information in forms which are not used internally or which require some conversion of scale, level, code, etc., to adapt them to internal use or external acceptance. Of particular importance are the external links required when an analog computer is operated with digital input or output.

Common examples of simple input links are mechanical knobs, cranks, and levers manually operated and rotating or push-pull shafts powered by various pickup devices. The electrical equivalents are rotary potentiometers and variable capacitors, toggle or rotary gang switches, and jack and plug cabling, for hand setting. Powered electrical inputs are usually voltages derived from associated transducers. More sophisticated input links are represented by the A, B, C tapes of the M.I.T. machine described in Section III: 6.

Simple output links frequently used are mechanical indicating dials, voltmeters, milliammeters, oscilloscopes, and curve-drawing recorders. Shaft or voltage outputs may serve for process control. More complex output links may produce magnetic or perforated tape records or punched cards, usually after digitizing. Component failure lights may be considered as logical output links.

Storage

Unlike digital storage which is mostly localized, analog storage may be identified with many parts of the computer where quantities are represented transiently or permanently. Very common examples of transient storage are the mechanical angular position of a rotating shaft and the electrical charge on a capacitor. As the shaft turns or the capacitor charges and discharges, the stored quantity changes and its past history is lost unless otherwise preserved. On the other hand, a locked shaft or a fixed voltage-dividing resistor can store values which are permanent until affirmatively altered.

Operations

The operations units are the heart of the computer and determine its character. The other units may be considered as merely serving the operations units. The operations may be both logical and numerical, although in current analog machines the logical patterns are usually built in or are manually effected by the operator.

Of great importance among analog operations are the *conversions* which are either necessary or desirable to permit or facilitate the interconnection of units operating in different modes. The modes may differ as to quantity representation form, scale factor, level, code, etc. An example of mechanical conversion of quantity representation between length and angle was given in the rack-and-pinion motions described in Section III:3. Another such conversion is a screw-and-nut arrangement whereby the turning of the screw (representation by angle) is converted to the linear motion of the nut (representation by length). These conversions are illustrated by Figures 3 and 4. An example of the conversion of a mechanical representation (angle) into an electrical representation (voltage) is shown in Figure 5. Conversion in the reverse sense (voltage into angle) is typified by the classical d'Arsonval movement, which is used in the great majority of voltmeters. In a voltmeter the voltage applied to the meter terminals is converted to the angular position of the pointer.

Conversions which are made to adjust scale factors are typified in mechanical devices by levers which increase or decrease linear displacements and by gear ratios which amplify or reduce rotations. In electrical devices, scale factors are commonly adjusted by attenuating impedance networks when a reduction is required (Figure 10) or by electronic amplifiers when an increase is needed.

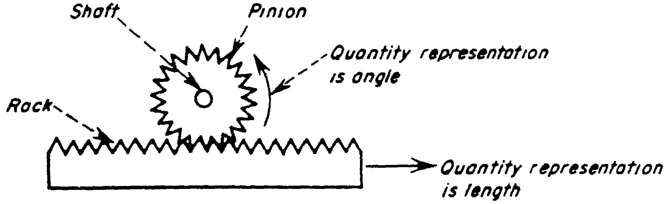

Shaft
Pinion
Quantity representation is angle
Rack
Quantity representation is length

Figure 3. Mechanical conversion of quantity representation by rack and pinion.

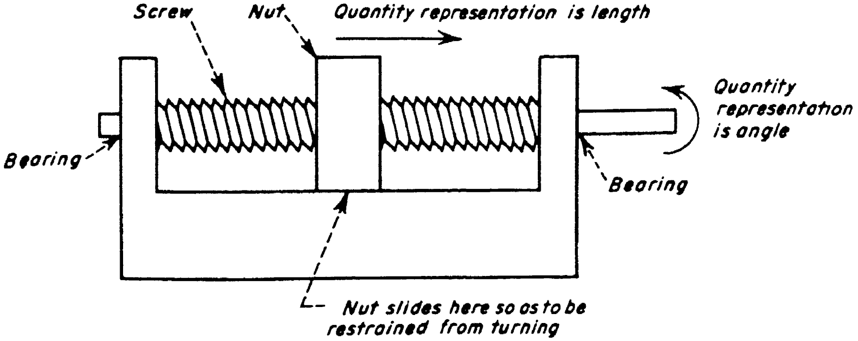

Screw
Nut
Quantity representation is length
Quantity representation is angle
Bearing
Bearing
Nut slides here so as to be restrained from turning

Figure 4. Mechanical conversion of quantity representation by screw and nut.

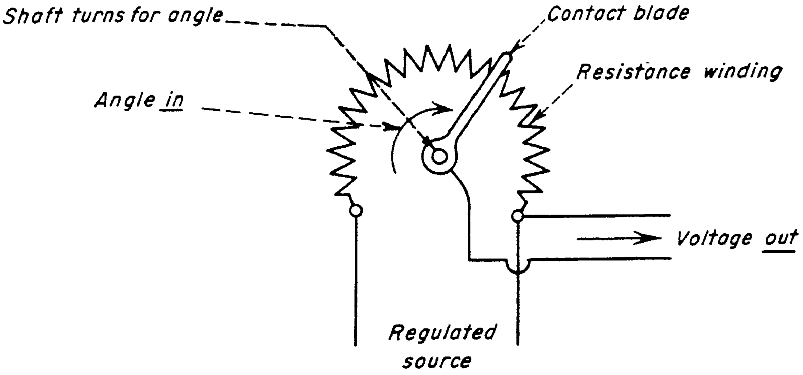


Figure 5. Electromechanical conversion of quantity representation by potentiometer.

Addition (subtraction) is an operation which is required in practically every computer. The ubiquitous slide rule performs addition (of two lengths representing logarithms) by the placing "end-to-end" of two representative lengths. Their outer ends are then separated by a length which is the sum of the two individual lengths.

Two useful methods for performing mechanical additions of lengths are illustrated in Figure 6. On the left of the figure, three pulleys and a chain show how the motions of two of the pulleys can be summed by the third. This principle can be extended to a large number of pulleys. They do not need to operate in parallel paths or be near together, as shown, provided the chain is properly led between them by means of idlers. On the right of the figure is shown a bar linkage method for summing displacements. It utilizes the pro-

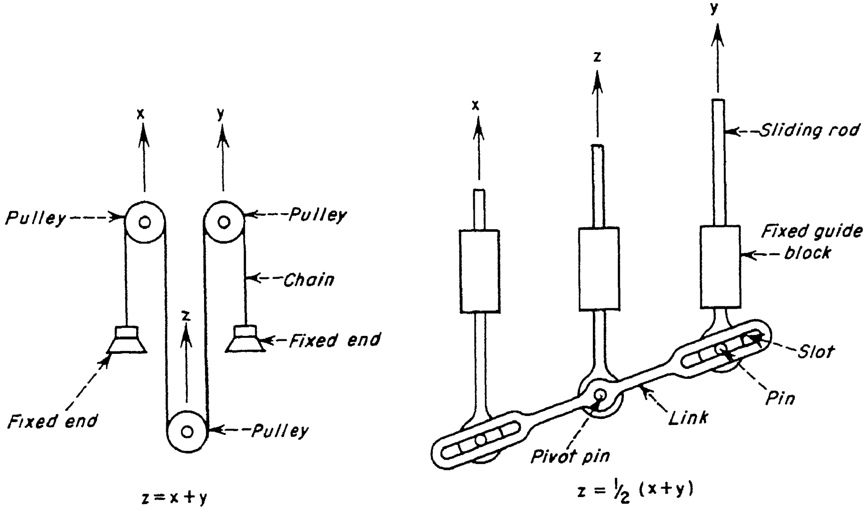


Figure 6. Mechanical addition of lengths by chain and pulleys (left) and by bar linkages (right).

perties of similar triangles. As shown, two lengths are added with equal weights. However, the weights can be adjusted to other values by different lateral spacings of the guide blocks. Moreover, additional addends can be accommodated by extending the principle.

In Figure 7 is depicted a means for the mechanical addition of angular displacements. It is one of the most widely used devices in mechanical analog machines. In fact, it is so convenient as a machine component that it is often used to add linear displacements (after the necessary conversion) instead of more direct methods such as those discussed in the paragraph above. The differential gear is sometimes puzzling upon first acquaintance, especially if it is stated to be an epicyclic gear train. Nevertheless, it is a simple device. It is even used on the rear axle of every motor vehicle. Here it permits the rear wheels enough independence to follow road curves. The wheel on the inside will be turning more slowly than its mate on the outside but both will be responding to the drive shaft. There are several designs of differential gears which accomplish the same result, but only the one illustrated in the figure need be considered. As drawn it consists essentially of four gears, A, B, C, D. There is a fifth gear, E, which is not a part of the differential gear proper but is frequently associated with it. Gear D may be denoted as the "spider" gear (its frame sometimes remotely resembles a web), and it carries one or more "planet" gears, C. The shaft to which gear D is keyed is seen extending to the extreme right and left of the assembly. Around this shaft are two collars, free to turn on it, each keyed to one of the two "sun" gears, A, B. The sun gears A, B mesh with the planet gear C and the spider gear D meshes with the auxiliary gear E. If gear B is held fast and gear A is turned clockwise, gear C will roll on gear B and carry gear D with it through *half* the angle by which gear A is turned. The reason for the factor ½ is similar to that explained for gear H of Figure 2. Likewise, turning gear B while gear A is held fast will turn gear D by half the angle and in the same sense. When both A and B are turned, D will turn for half the sum, i.e., if A is turned through angle a and B through angle b, D will turn through $\frac{1}{2}(a + b)$. Finally, if the pitch diameter of D is twice that of E, then E will turn through $a + b$. As indicated by the arrows in Figure 7, correct account of the senses of the angles must be observed. The overall result is a means for adding (or subtracting) angles without limit.

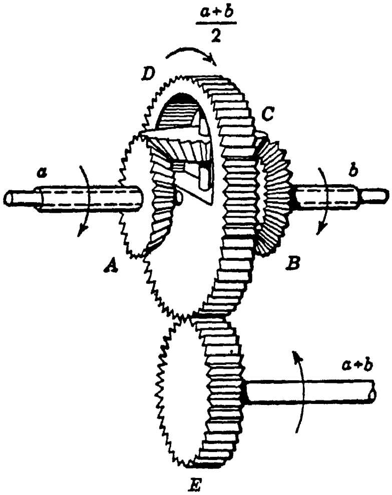
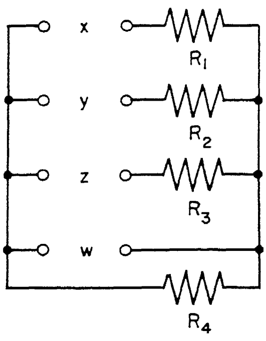


Figure 7. Differential gear assembly.

Electrical addition of voltages is most often effected by utilizing the superposition principle in an impedance network. This principle is that when two or more voltage sources are present in a linear network, each source can be treated in turn as though all others were of zero voltage (retaining, however, their internal impedances as passive network elements). The resulting currents, with their attendant voltage drops, as determined for each source separately, can then be added to arrive at the overall effect. In other words, the current through any loop, or the voltage at any node (junction point), is the sum of the currents or voltages set up by the several sources independently. It is important to note the requirement that the network elements must be linear, such as common resistors; otherwise, the superposition principle does not apply and the overall effect will not be the simple sum of individual effects.

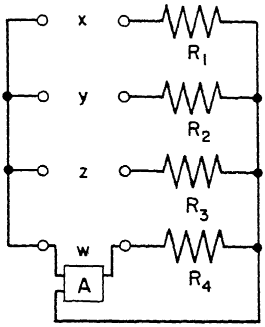
An example of electrical addition is given in Figure 8. The voltage w is the sum of the source voltages x, y, z, each multiplied by a constant coefficient which depends only upon the values of the R's (the impedance of each of the three sources being assumed as either virtually zero or as included in its series resistor value.) The superposition principle is exemplified by the fact that the sum voltage, w, is the combined drop across resistor R_4 due to the source voltages x, y, z acting together. In particular, if all the R's have the same value, the k's will all have the value ¼, i.e., $4w = x + y + z$.



$w = k_1 x + k_2 y + k_3 z$

Figure 8. Electrical addition of voltages by resistance network.

Another example of electrical addition is shown in Figure 9 which is obviously similar to the previous figure. However, in Figure 9 an amplifier, A, has been added and R_4 plays a different role. R_4 is now another series resistor (like R_1, R_2, R_3) for the source w (the amplifier output). The source w furnishes just the right amount of drop across R_4 and in the right sense to balance (almost exactly) the sum of the voltages appearing, due to sources x, y, z, at the junction of R_1, R_2, R_3 with R_4. Consequently, the junction of the



$$-w \doteq k_1 x + k_2 y + k_3 z$$

Figure 9. Electrical addition of voltages using an amplifier.

four resistors is (almost exactly) at zero voltage. This almost zero voltage is led to the amplifier input and is used to control the amplifier output (source w) so that it fulfills the requirement stated above. This is, that the drop across R_4 balance the sum of the voltages from R_1, R_2, R_3. The amplifier, of course, makes the balance automatically. The gain of the amplifier is usually very high so that only a trivial unbalance voltage is required at the input to adequately control the output. However, because a slight departure from an exact balance is inherent in the method, the sign of approximate equality is used in the formula of Figure 9, rather than the sign of exact equality. The k's of the formula depend only upon the R's, with the same proviso as before that the impedances of the sources are negligible, or are considered as included in the R's. If the R's are equal, the k's are 1, i.e., $w + x + y + z \doteq 0$.

Multiplication, next to addition (subtraction) is, perhaps, the most common mathematical operation. Its inverse, division, will be considered separately. Multiplication can be effected very simply in some cases, while in others it tends toward complexity. There are two important considerations in this respect: Firstly, whether the multiplicand or the multiplier or both must be variable, and if so, whether discretely or continuously, and secondly, whether the product requires resetting or can be continuously generated. The reasons for these considerations should be clear from the examples which follow.

Perhaps the simplest and most common example of mechanical multiplication is a fixed gear ratio. This can be used to increase or decrease the scale factor of angular quantity representations. However, one factor (the gear ratio) remains fixed unless gear shifting is resorted to. Quick reset of the product requires additional mechanism. Simple lever mechanisms for multiplication of linear displacements are also very common and effective but tend to be as inflexible as gear ratios so long as they remain simple.

Very common examples of electrical multiplication by a fixed factor are a voltage-dividing resistor, Figure 10, and a transformer, Figure 11.

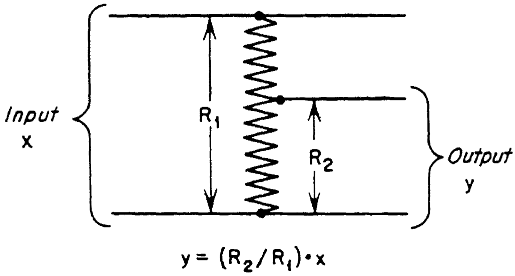


Figure 10. Electrical multiplication by resistors.

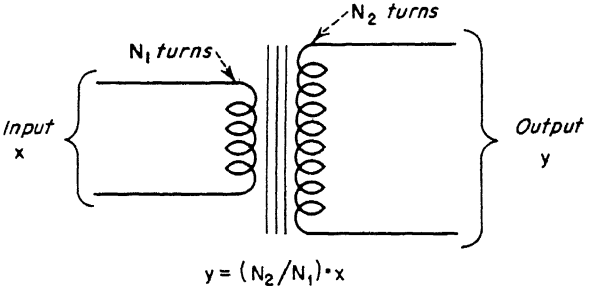


Figure 11. Electrical multiplication by transformer.

Mechanical multiplication by a factor which can be varied throughout a continuous range of values is exemplified by Figure 12. The device has been used in automobiles where it was known as a "planetary" transmission. It afforded control over the speed from full ahead, through stop, to full reverse. The shaft of the wheel is parallel to a diameter of the disk and its edge contacts the disk at a controlled radius, a, as indicated. When the disk is rotated, the wheel is rotated by it unless the point of contact is at the center of the disk ($a = o$). For a given value of a, the rotation of the disk, x, will cause a rotation of the wheel, y, equal to x multiplied by a/b.

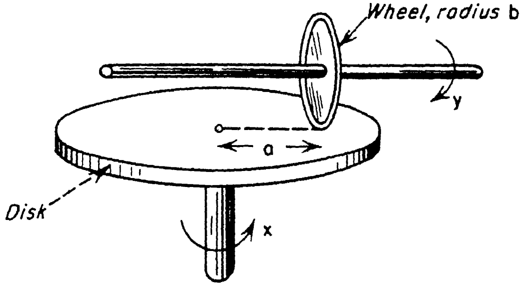


Figure 12. Disk and wheel device.

Thus, by setting a/b (multiplier), rotation x (multiplicand) produces (product) rotation $y = (a/b)\,x$. However, it is to be observed that if x has been multiplied by a given value of a/b to produce a rotation $y = (a/b)x$, and a new value of a/b is set, the value of y up to that time is not affected. Further rotation of x with the new a/b will increase y (or decrease it, depending upon the direction of x) according to the new a/b. That is to say, the device multiplies *increments* in x to produce *increments* in y. Hence, if a/b is to be changed during a problem, and it is desired to have y represent total x multiplied by the latest a/b, it will be necessary to reset x to zero when a/b is changed and then run x up again to its current value. Generally, this would be an impractical procedure and other means of multiplication would be used. The device of Figure 12 is one form of a number of such devices which are frequently referred to as *variable speed gears*. They have other mechanical forms, and even hydraulic counterparts, any of which is potentially usable for multiplication. They also are potentially available for the operation of integration, as will be discussed later.

Electrical multiplication by a factor which can be varied throughout an essentially continuous range of values is indicated in Figures 13, 14, and 15. In Figure 13, the principle is an extension of that in Figure 10, with an adjustable potentiometer substituted for fixed resistors. Similarly, Figure 14 derives from Figure 11, the number of effective turns in the secondary winding, N_2, being adjustable by sliding contact. In Figure 15, a special form of transformer known as a *resolver* is indicated. A resolver is built something like an electric motor and may have, as shown, three windings. The input winding is on a rotor and the output windings are on the stator in electrically perpendicular locations. Turning of the

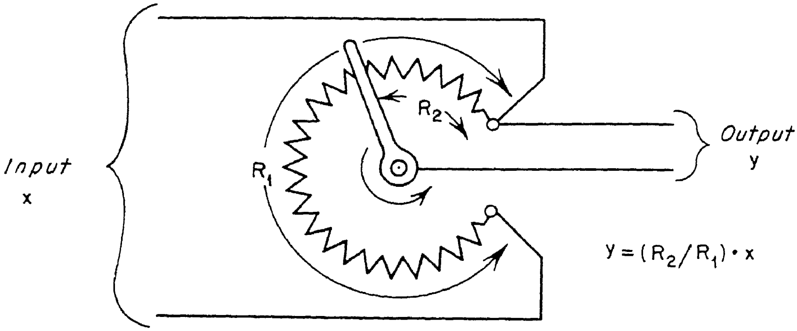


Figure 13.

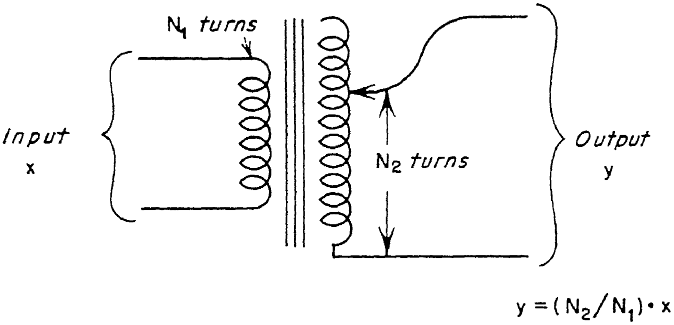


Figure 14.

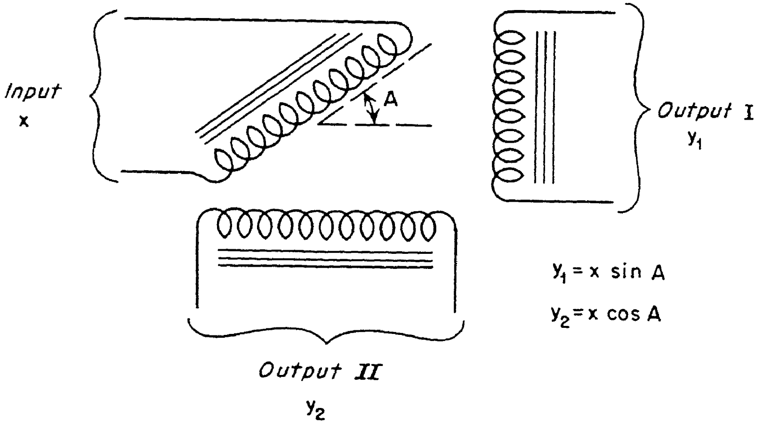


Figure 15.

rotor varies the coupling between the windings so as to produce the sine and cosine functions. It is to be noted that in all three of the devices shown in these figures, a mechanical motion (of a contact or a rotor) is necessary to change the multiplier factor (R_2/R_1, N_2/N_1, sin A, or cos A). This mechanical motion may be supplied manually or by servo, but the need for it limits the use of these devices to relatively low-speed applications.

Mechanical multiplication in which both the multiplicand and the multiplier can vary continuously can be performed by using the principle of similar triangles. The essentials of one form of such a device are depicted in Figure 16. The device is essentially flat and consists primarily of three movable slots, H, V, and S, which define some of the sides of the triangles used. Slot H is always horizontal and can be moved only up and down as indicated by the z arrows at the left of the figure. Slot V is always vertical and can be moved only right and left as indicated by the x arrows at the bottom of the figure. Slot S is pivoted at point A and can only swing about that point. The three slots are joined by a pin E which is free to slide in any of the slots but insures that all three will intersect in a single point. When slots V and S are positioned, slot H is forced to move so as to pass through their intersection. Slot S is positioned by pin C which can move only up and down along the line BC. The restraints which limit the motions of the slots and pin C to those just

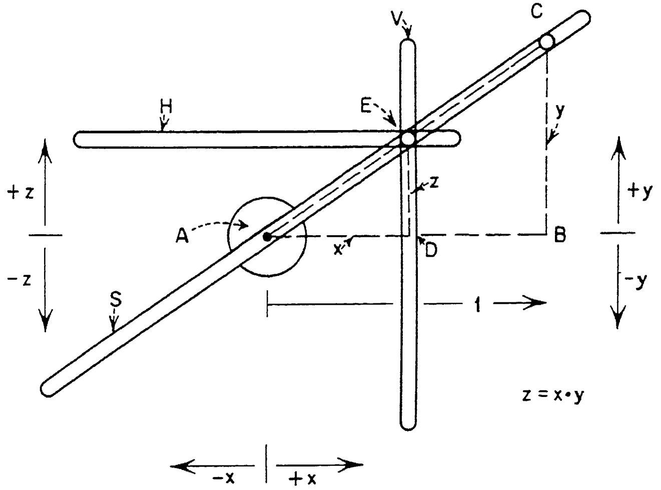


Figure 16. Mechanical multiplication by similar triangles.

described are not shown. The triangles used are indicated by dashed lines and are ABC and ADE. These triangles are similar and hence $AB/BC = AD/DE$. The length AB may be considered as unity (1). Slot V is positioned by an x input so that $AD = x$. Slot S is positioned by pin C which in turn is positioned by a y input so that $BC = y$. Pin E moves slot H so that $DE = z$. Because of the proportion given above, $1/y = x/z$, or $z = xy$, and the z motion of slot H is the desired output. The device as shown is theoretically exact, but certain variations of it have proven more practical as mechanisms. An approximate equivalent can be made from bar linkages.[1]

Electrical multiplication in which both the multiplicand and the multiplier can vary continuously (i.e., an electrical counterpart of Figure 16), but for which mechanical motion such as in Figures 13, 14, and 15 is excluded, becomes quite complex and will not be covered here.[2]

Division is an inverse operation and hence tends to be more difficult to mechanize. It can often be avoided by rearranging the formula to be implemented. The device of Figure 16 can be operated as a divider but none of the other multipliers mentioned can be so used directly. However, any multiplier can effectively become a divider by using an implicit function technique. This is discussed in Section III: 7.

Integration is the name for the operation in which addition is performed at a varying rate. The concept is quite simple but its mathematical trappings often make it seem confusing. That is to say, what is being done is quite elementary; how it is being done by mathematical manipulation is frequently very complicated. Fortunately, mechanized integration exhibits the essential nature of the operation by very simple devices, so the confusing mathematical symbols need not be a bar to a clear grasp of it. On the contrary, when the action of the mechanism is understood, the meaning of the basic symbols should stand revealed. An everyday example of integration is encountered whenever one rides in an automobile. The distance travelled is added to bit by bit, sometimes at low speed, sometimes at high speed. The speed is the time rate of adding distance, i.e., in technical language, the speed is the time derivative of the distance. The speed usually varies up and down, so the rate of adding distance goes up and down, but always the total distance traveled is strictly the time integral of the speed between the start and stop of the reckoning. Thus, the automobile literally and exactly performs an integration. To get the same result with analytical mathematics might be a fancy undertaking, but the automobile as an analog device has no difficulty and is certainly not difficult to comprehend, at least is this connection.

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[1] Svoboda, Antonin / "Computing Mechanisms and Linkages", Mass. Inst. of Technology, Radiation Laboratory Series, vol. 27 / McGraw-Hill Book Co., New York / 1948, 299 pp

[2] Edwards, C.M. / "Survey of Analog Multiplication Schemes", Journal of the Association for Computing Machinery, vol. 1, no. 1, pp 27-35 / Jan. 1954

Mechanical integration can be performed by the disk and wheel device of Figure 12. It was presented (p. 100) as a multiplier; however, it was noted that in practical use as such, the distance a should remain fixed during a problem because the device actually multiplies *increments* of x to produce *increments* of y. These increments of x can be as small or as large as required. If we consider them as exceedingly small, or "infinitesimal," we denote each by dx. When the disk turns through the input infinitesimal angle dx, the construction of the device assures us that the wheel will also turn through an output infinitesimal angle. This output is a/b times the size of dx, i.e., the angle is $a/b\ dx$, and we denote it as dy. Thus, $dy = a/b\ dx$. In other words, the tiny amount, dy, added to y for each dx can be varied by controlling a and hence a/b. Let us suppose that the scale of representation is such that $b = 1$; then we can write $dy = adx$, thus simplifying the discussion to follow. We consider that there are two inputs to the device, dx and a, and one output $dy = adx$. If we continue to put in dx's (i.e., turn the disk) and vary the a's, we will get out a series of dy's of varying size. The sum of all the dy's will be represented by the total rotation of the wheel; its shaft can turn a calibrated dial to show this total. If we call the starting position of the dial y_0 and its position at some later time y_1, then its total rotation will be their difference, i.e., $y_1 - y_0$. Now this sum of all the dy's, which is equal to $y_1 - y_0$, was obtained just by turning the disk while moving the wheel out and in (varying a). But $y_1 - y_0$ is technically the integral of dy and is formally written:

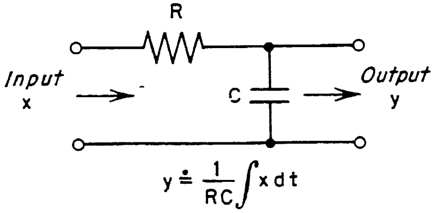
$$y_1 - y_0 = \int_0^1 dy = \int_0^1 adx.$$

In application of the device in a computer, the variable *a* would represent a quantity which is to be integrated with respect to x. For example, if x is driven by a clock motor so that it represents time to some suitable scale, and *a* is varied to simulate the speed of the automobile of our everyday example, then *y* will represent the distance traveled. The device will then be an analog for the automobile as to time-speed-travel.

The foregoing description of a mechanical integrator has been made rather extensive because experience has indicated that the concept of integration is sometimes difficult to the uninitiated. To repeat what was said above, the concept is really quite simple (and useful). It is only when one tries to apply it analytically rather than mechanistically that real difficulties may arise.

Electrical integration, like its mechanical counterpart, is a process of summing at a varying rate. The summing device is basically a capacitor into which electric charge is fed (or from which it is removed) at a controlled rate. As more charge is added to the fixed capacity its voltage rises in direct proportion. The voltage across the capacitor at any instant is, therefore, a representation of the total charge, i.e., of the integral of the charging rate. Application is made by controlling the charging rate so that it represents a quantity to be integrated. The capacitor voltage then represents the integral of that quantity. For example, if the capacity is one microfarad (a common value) and the charging is done at 100 microcoulombs per second (a reasonable rate), the voltage will be 100 volts at the end of a second. However, the charging rate will usually not be constant, which is the reason that integration is required and is obtained by this device.

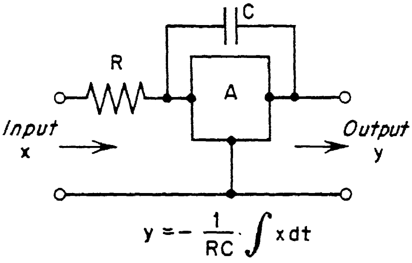
A commonly used circuit for electrical integration is shown in Figure 17. The charging of the capacitor C is effected by the input voltage x sending a current through the resistor *R*. Now x volts, ac-



$$y \doteq \frac{1}{RC}\int x\,dt$$

Figure 17. Electrical integration by capacitor and resistor.

cording to Ohm's Law, can send x/R amperes through resistor R, and in one second this would amount to x/R coulombs of charge. The x/R coulombs in C farads gives a voltage of x/RC, which explains the coefficient of the integral in the formula under the figure. The formula is not an exact relation, however, but an approximation. This is so because as the charge is built up in C and its voltage rises, the built-up voltage opposes x and reduces the flow rate. We can ignore the effect if it is small enough in some application, but usually it is offset by using a feedback amplifier. The amplifier will generally be needed anyway to avoid placing any appreciable load on the output, for a load would remove charge from C and affect the integration. The modified circuit is indicated in Figure 18. Additional circuit considerations, including the effects of capacitor leakage, will be found in other sources.[3]



$$y = -\frac{1}{RC}\int x\,dt$$

Figure 18. Electrical integration with amplifier.

It is to be noted that the electrical integrators perform on a time basis, i.e., x and y are both functions of time and are therefore, in a sense, tied to the clock. This is contrasted with the mechanical integrator for which the turning of the disk (at whatever practical rate) generates its own pseudo-time. The mechanical integrator can hence be more freely disposed in a functional array than can its electrical counterpart.

Differentiation is the inverse of integration. In formal mathematics it is much the easier to perform of the two operations, but in mechanized computing the reverse tends to be the case. In the mechanical field there is no really practical differentiator for conventional computer purposes and reliance is placed on implicit function operation (Section III:7). Differentiation is the process of finding the rate at which one quantity varies as some other related quantity varies. In our everyday example of the automobile, the rate at which the distance traveled increases as time elapses is obtained by "differentiating" the travel "with respect to time." Of course, this rate is known as the speed, and the differentiation is performed by the speedometer. It is a true differentiator, and a related electromechanical effect (tachometer generator) is used in some computers.

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[3] Greenwood, I.A., J.V. Holdam, Jr., and D. MacRae, Jr. / "Electronic Instruments", Mass. Inst. of Technology Radiation Laboratory Series, vol. 21 / McGraw-Hill Book Co., New York / 1948, 708 pp; Korn, G.A., and T.M. / Electronic Analog Computers / McGraw-Hill Book Co., New York / 1953, 372 pp.

A common electrical differentiator circuit is quite similar to that for integration. In Figure 19, a change of input voltage *x*, say by the small quantity *dx*, will tend to cause a corresponding change in the charge in the capacitor, *dq*, and this equals *Cdx* by the fundamental law. If the small change *dx* takes place in the correspondingly small time *dt*, the ratio *dx/dt* is the rate of change we seek by differentiation. Now, for the charge in C to change by *dq* in time *dt*, a current *i* must flow for time *dt*, that is, $dq = idt$ by definition of a current. We now have two expressions for *dq*, namely *Cdx* and *idt*, and they must be equal, hence $Cdx = idt$, or $i = Cdx/dt$. The current *i*, flowing in resistor *R* will, by Ohm's Law, cause a voltage drop *Ri*. Using the above expression for *i*, we have $Ri = RC\ dx/dt$. But *Ri* is the output voltage *y*, and therefore $y = RC\ dx/dt$ as indicated in Figure 19.

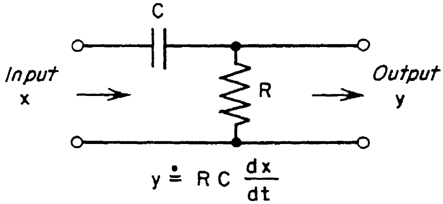

Figure 19. Electrical differentiation by capacitor and resistor.

The simple circuit of Figure 19 has a difficulty like that encountered in the circuit of Figure 17. The drop across *R* opposes the required flow of charge and results in the formula's being approximate only. Again, an amplifier with feedback is called for (Figure 20), and the remarks made as to integration have their counterparts as to differentiation. However, a circuit such as that of Figure 20 is apt to be more troublesome than that of Figure 18.

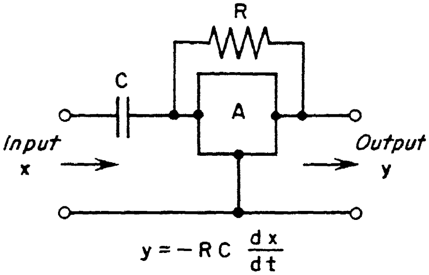

Figure 20. Electrical differentiation with amplifier.

Function generation is another operation frequently required in computers. For example, a computer may require the value of a dependent quantity, y, which varies as the sine of an independent quantity, x. In other words, the computer must mechanize the function $y = \sin x$. Another computer may have to deal with an empirical function for which no simple expression exists. For instance, a ballistic computer uses the Gâvre function which relates the retardation of a projectile to its speed through the air.

A simple mechanical function generator is typified by the Scotch yoke device, indicated in Figure 21, which generates the sine function. This function is, of course, readily available in electrical computers when the independent variable, x, is time, and the dependent variable, y, is a voltage or current. Common socket-power AC has a sine waveform, and oscillators tend to produce their output in the same form. When time is not the independent variable, other means can be used, such as the resolver or Figure 15.

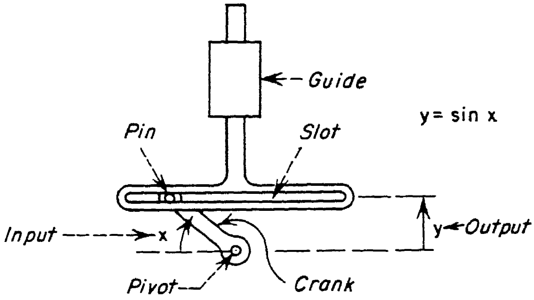

Figure 21. Function generation by Scotch yoke.

Empirical or arbitrary functions are readily mechanized by means of cams as depicted in Figure 22. The electromechanical counterpart is the tapered potentiometer of Figure 23. Other means of generating such functions are often quite complex.

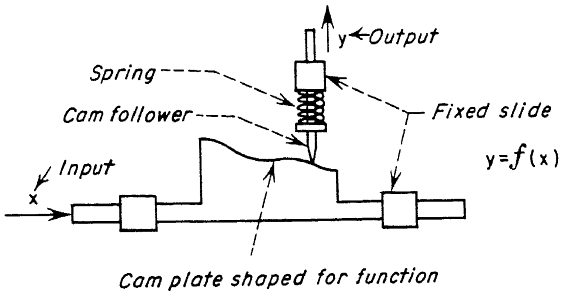

Figure 22. Function generation by cam.

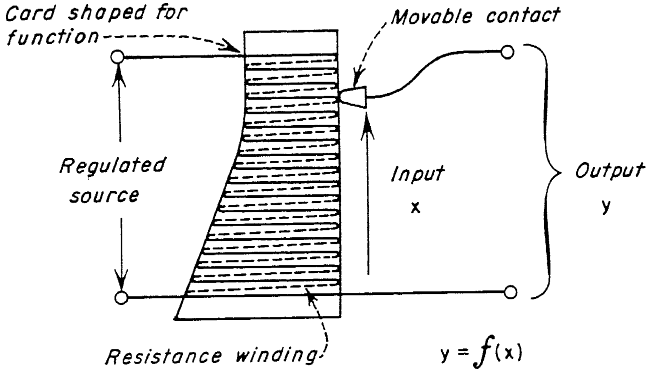

Figure 23. Function generation by tapered potentiometer.

The functions so far considered are functions of one independent variable or parameter. Functions of two or more parameters may be required. If so, it is likely that the analog computer will enjoy an advantage over its digital counterpart in this connection, as indicated above (p. 88). A mechanical generator for which the dependent quantity, z, is a function of two independent quantities, x, y, is shown schematically in Figure 24. On the electrical side, the instantaneous amplitude of an alternating current is a function of its maximum amplitude and its phase, independent parameters which can be separately varied.

Branch point operations are at least not commonly exploited in analog computers although they are very important in digital procedures. A branch point operation is one in which the value of a

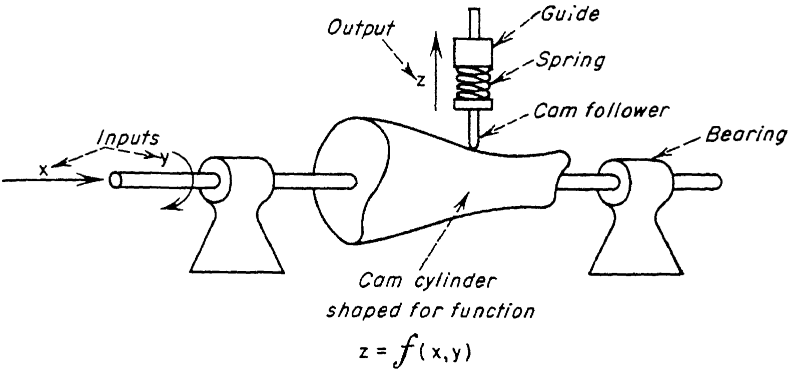

Figure 24. Function generation by 2-dimensional cam.

quantity arising in a problem is used to determine the ensuing portion of the program depending upon the value occurring. For example, a dependent variable y may be governed by the formula $y = x^2$ in the initial portion of a problem, but by $y = x^3$ when x equals or exceeds, say 1.5. The value $x = 1.5$ is then a branch point, and when x reaches 1.5 it should automatically transfer the y mechanism from the square to the cube law. In the mechanical field, branch points can be handled by such devices as clutches, gear shifts, and so forth. In electrical applications, relays and electronic switching are available.

Transfer

The element by means of which quantity representations of numerical data and logical instructions are transferred from point to point as needed in a computer consists of two features: the channels by which they are carried and the switches by which the channels are assembled into the required arrays. In a mechanical computer, the commonest examples of channels are wires, chains, or links. Using these, linear displacements are transmitted by pulling and pushing. Shafts and gearing carry rotations. Examples of mechanical switches are connectors such as hooks by which wires or chains can be attached to eyes or pins on the parts they are to be moved by or to move. Clutches or sliding gears are the means by which the connections of rotary shafts can be made or broken.

Electrical channels are almost entirely conventional electric wiring. Switching, besides electric switches proper, takes such forms as plug-and-jack connectors, relays of various sorts, and electronic circuitry. Crystal and tube diodes are used to admit or inhibit signals but their largest applications are digital.

Synchro transmission of rotary information is quite common. The instruments themselves (generators, motors, etc.) may be considered as operational conversion units and their connecting circuits as transfer units. There are several synchro systems, some based on DC and others on AC. The transmitting generator and receiving motor are frequently identical as to structure. The generator converts an angular position into a set of electric signals which the motor reconverts into an angular position. Transmission between units is usually by three-wire circuit. Sets of units are often operated in parallel, one set transmitting coarse data and the other a finer version of the same data.[3a]

Control

The function of the control element is to insure compliance with program. The program may be wholly built-in and fixed in a special purpose machine, or it may be quite flexible in one intended to handle a large class of problems. In any event, the machine in effect must be instructed what to do and must then do it. The programming of an analog machine, insofar as it is not structurally predetermined, tends to be a manual operation. In a mechanical computer, levers and knobs are set, clutches are operated, and gears are shifted. In an electrical computer, switches are thrown, jumpers are plugged in, and potentiometers are set. In short, the programming function is not mechanized to the same level as in digital machines. A notable exception to this tendency is the second M.I.T. differential analyzer discussed in Section III:6. The need for greater facility in programming is evidenced by the increasing provision of plug-boards which at least permit the presetting and retention of most of a program for an electronic differential analyzer or similar computer.

Monitoring is the follow-up portion of control. A wide variety of devices may be included to report if the computer behaves improperly, either functionally or physically, and perhaps to take appropriate action automatically. They may also report the status of problem solution. A very common example is a light to report an overload condition. Another example is a device to stop operation and give an alarm when a synchro unit drops out of step.

[3a] Details of the system can be found in Greenwood, Holdam, and MacRae, *loc. cit.*

Checking is a special form of monitoring. Checking devices can be incorporated in a computer to give notice or take action if selected mathematical relations are violated. For example, in a machine which computes the angles of a triangle, a checking unit could continuously determine the sum of the angles computed, and sound an alarm if the sum departs from 180 degrees in excess of tolerance.

Timing may be an important feature of the control. A computer may operate in "real time," i.e., concurrently with, or at the same speed as, some system for which the computations are being performed. An example is a navigational computer which continuously reports a vehicle's present position, as in Omnirange (for aircraft guidance). Other computers may be too slow to follow real time, and still others may be capable of operating much faster than the system analoged. Many computers can be so operated as to keep their own "machine time," which may or may not be matchable to real time. In many cases, time will not be a factor in the problem, and operating speed will be set so as to optimize machine performance and minimize the tying up of personnel and equipment.

Power Supply

As already noted, power supply may range from minor manual effort to extensive electrical systems. The motors, transformers, rectifiers, regulators, and so forth, are not essentially peculiar to computer applications, so no specific examples are required here. It suffices to note here that the power requirements may be unexpectedly large and should be adequately anticipated.

III:6 EXAMPLES OF ANALOG COMPUTERS

We shall now consider how the units of Section III:5, or similar units, can be assembled into machines for solving problems. Principal attention will be given to machines known as *differential analyzers*. Both a mechanical and an electronic version will be presented. *Harmonic analyzers* and *synthesizers* will also be discussed.

Differential Analyzers

Computers denoted by this name or its equivalent are important because of their wide use in scientific and engineering applications. They are of particular interest because they afford an excellent opportunity for acquiring a real insight into the processes with which they deal. These processes are often confusing in mathematical dress but are readily understandable in their mechanized forms. This type of computer is historically significant, for it was its introduction and rapid, world-wide acceptance which did much to initiate the present era of elaborate computers. Now there are many kinds, analog and digital, mechanical and electronic, and their numbers are legion. Before the advent of the first differential analyzer at Massachusetts Institute of Technology, computers were either relatively simple, special purpose, or experimental laboratory types. After its successful introduction, the construction and application of complex multipurpose computers became an increasingly popular undertaking. The possibilities of mechanized computing were exploited more and more extensively and intensively.

The stories of Aiken's Harvard Mark I and of Eckert and Mauchly's ENIAC are told elsewhere in this book. These digital machines were anticipated in principle by the work of Charles Babbage in the early 1800's. Likewise, in the late 1800's, Lord Kelvin suggested the basic principles of the differential analyzer. Both Babbage and Kelvin were, however, handicapped by the lack of the modern techniques available to today's designers.

The first "differential analyzer" so named, was completed at M.I.T. in 1930 under Dr. Vannevar Bush (later the distinguished head of the Office of Scientific Research and Development during World War II, and President of the Carnegie Institution of Washington). He had preceded it by a number of less powerful "integraphs," but eventually adopted many of the concepts incorporated in the "ballistic engine".[4] This was invented in 1923 and communicated to Dr. Bush in 1924. The ballistic engine was a virtual prototype of the differential analyzer except that the former was special purpose for exterior ballistic problems whereas the latter was intended to handle general problems. While both machines were indebted to the prior art, neither stemmed directly from Kelvin's work. This work was not known to Dr. Bush or to the author of "A Ballistic Engine" at the time.*

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[4] Wainwright, Lawrence / A Ballistic Engine / University of Chicago, Master's thesis, not published / 1923, 28 pp.

The primary purpose of a differential analyzer is to solve differential equations. "Differential" equations are equations in which the rates of change of quantities are involved. We must deal with such equations because many of the laws of nature are known in terms of rates of change rather than directly in terms of the quantities of interest. In solving such equations we seek to eliminate the rates and determine therefrom relations among the quantities themselves. For example, a falling body (under certain simplifying assumptions) obeys the law that the acceleration is constant (g, the acceleration of gravity). In other words, the distance fallen, h, increases with time at a certain rate (denoted by dh/dt), but this rate, dh/dt, itself increases with time at a rate (denoted by d^2h/dt^2) which has a constant value, g. In still other words, the law is that the rate of change *of the rate of change* is a fixed amount. Written as an equation, this is $d^2h/dt^2 = g$. Assuming that the body falls from rest, a "first integral" of this equation is $dh/dt = gt$. In words, the time rate of change of distance equals g multiplied by the time of falling. Then, counting h from the beginning of the fall, a second integral gives $h = \frac{1}{2}gt^2$. Again in words, the distance fallen equals $\frac{1}{2}g$ multiplied by the square of the time of falling.

In the foregoing example, we started with the law of falling bodies, which law involved rates of change. We then proceeded to find a relation between the time of falling and the distance fallen. This relation involved no rates of change. This process was a simple instance of the *analytic* solution of a differential equation. If its meaning is not clear in this symbolic form, it should become so later when we see how it is done mechanically. The formula $h = \frac{1}{2}gt^2$ is a neat package, convenient for mathematical manipulation. However, such neat solutions to differential equations are not available in many practical problems. In fact, the practical problems which can be solved by analytic methods are only a tiny fraction of those for which solutions are needed. The needed solutions in the large majority of cases can, however, be found by numerical methods, digital or analog. These solutions will lack the generality of the analytic ones, for they will be solutions for particular values only. They will lead, not to formulas, but to numerical tabulations and graphic presentations. Nevertheless, they will have great value.

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*In a private communication to Wainwright, Dr. Bush wrote (Nov. 14, 1935): "I have become quite familiar with the literature of this subject, and as far as I know you were the first after Kelvin to proceed in study along these lines and the first to suggest a machine elaborated in detail for the handling of the ballistic equations."

The analog solution of differential equations to be discussed here will include both mechanical and electronic methods. These examples will deal only with the class of differential equations styled "ordinary." This is distinguished from "partial" differential equations, for the meaning of which the reader is referred to textbooks on the subject. Ordinary differential equations are those in which there is only one independent variable, most frequently time (t), while all the other variables are dependent variables.

The M.I.T. Differential Analyzer

The first differential analyzer completed at M.I.T. was a tremendous contribution to the field of mechanized computing. It inspired the construction of many similar machines. The experience gained from it clearly indicated the need for a more powerful and flexible machine. Such a machine was constructed, and publicly announced in 1945.[5] It is this second machine which will be discussed here. For brevity, we shall refer to it as MIT II.

The MIT II is considered a mechanical analog computer for solving ordinary differential equations. However, in what follows, it will be found that it is not solely mechanical but also makes extensive use of electric (including electronic) methods. Nor is it solely analog, for many of its features are digital. And, moreover, it can solve some problems which are not essentially differential equations. It is true, though, that its main reliance is on mechanical analog methods, and its greatest utility is in dealing with differential equations. Its basic quantity representations are mechanical angles and lengths, although these are frequently converted into electrical equivalents.

The most essential units of MIT II are its integrators, of which eighteen are provided. This is basically the disk and wheel (variable speed) device of Figure 12, but great ingenuity and pains have been devoted to making it a precision mechanism. In particular, the take-off of wheel rotation is effected by an electrostatic *angle indicator*. This imposes virtually no load at all on the turning of the wheel (any sensible load would militate against accurate integration).

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[5] Caldwell, S.H., and Vannevar Bush / "A New Type of Differential Analyzer" in Journal of the Franklin Institute", vol. 240, no. 4, pp 255-326 / Franklin Inst., Philadelphia, Pa. / Oct. 1945, printed.

The units next in importance are those used for adding. Their basic mechanism is a differential gear similar to that shown in Figure 7. These adding units, which will sum two or three input angles, are made up into a variety of components and include other features besides the basic differential gears. One of these features is a *gear box*, one for each input. This is a remotely controllable gear shift for applying a fixed multiplier factor to the input. Another feature is servo operation by which each input angle is powered by a servo motor. The motor is under control of a receiving (electric) angle indicator. A third feature is that the output of the summing differentials is taken off by a transmitting (electric) angle indicator. Thus, the addition these units do is performed mechanically, but they receive their inputs and deliver their outputs electrically.

Besides units to integrate (disk and wheel) and units to add (differential gears), many other facilities are needed. Several of these other facilities will be presented in examples of the manner in which the machine operates, but some will be ignored as not important to a grasp of the general principles. In particular, we shall tend to ignore the fact that the units of the machine are largely servo powered and are interconnected electrically by elaborate switching mechanisms. Instead, we shall make our diagrams, and conduct our discussion, as though the machine were entirely mechanical and largely friction-free.

As a first example, consider the falling body discussed on page 115. The situation is illustrated in Figure 25 and the differential analyzer setup is shown schematically in Figure 26. In Figure 26 there are two integrators, four shafts with a counter each, a hand crank, and a motor, all connected as indicated. The lowest shaft, by its angular position as shown on its counter, represents the quantity ("independent variable") *t*. It is powered by the motor and powers the disks of the integrators. The infinitesimal increments of rotation of the disks therefore represent *dt*. The next lower shaft represents

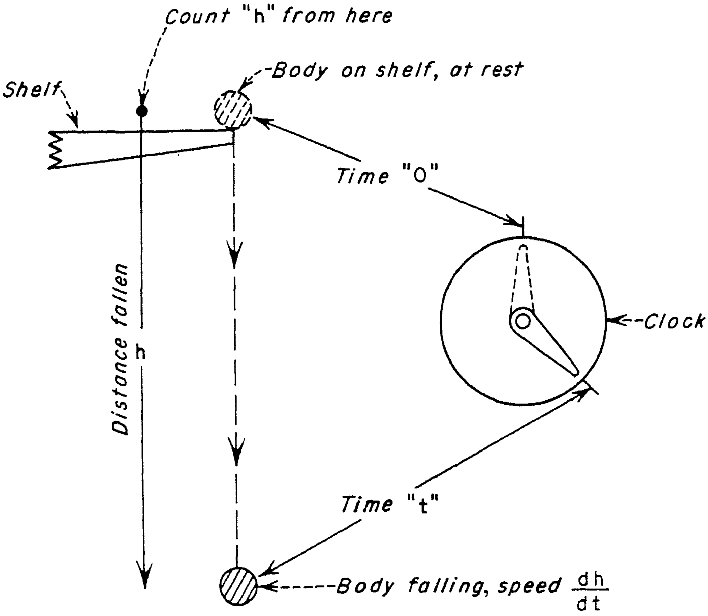


Figure 25.

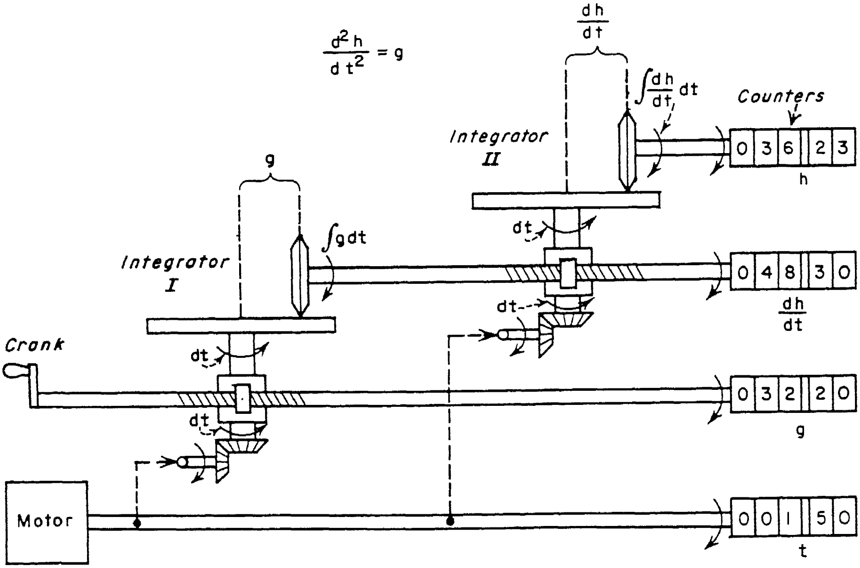


Figure 26.

g as set by the crank and shown on the counter. When g is set to its fixed value, the screw on its shaft displaces the disk axis of integrator I to the left. As a result, the wheel of integrator I operates at a radius which equals g to the scale used. This wheel then turns (as dt's are fed into the disk) so as to put out

$$\int g dt = \int \frac{d^2h}{dt^2} dt = \frac{dh}{dt}.$$

These equalities are due to the equation for which we have made the setup. The next to top shaft receives dh/dt from the wheel of integrator I and uses it to position the disk of integrator II and to operate the dh/dt counter. The wheel of integrator II, being positioned at a radius representing dh/dt, is turned by the dt's fed into the disk so as to put out $\int \frac{dh}{dt} dt = h$. This is transferred by the top shaft to the h counter. The h, dh/dt, and t counters are set to zero, and the g counter is set to its fixed value, before the run is started. This is done because we assumed that h and dh/dt start from zero at zero time and that g is a constant. As the run progresses, corresponding values of t, dh/dt, and h are recorded in either tabular form (Table 1) or graphically (Figure 27). These are the answers sought.

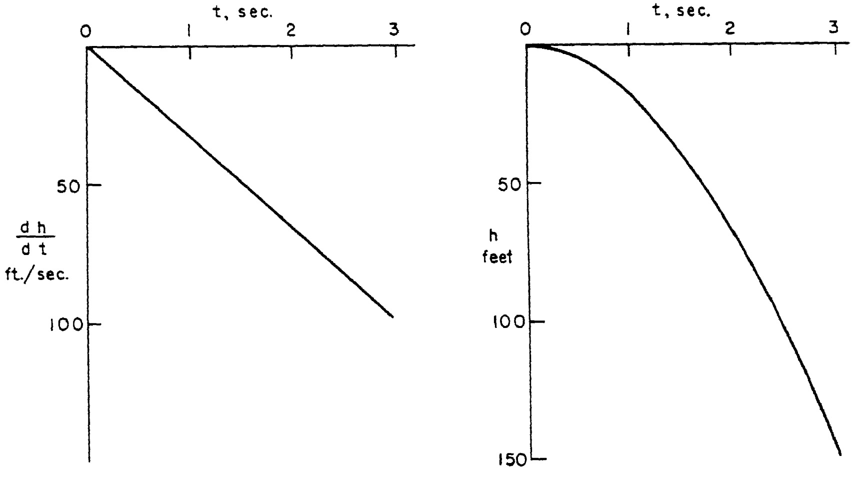


Figure 27.

TABLE 1

t, sec	dh/dt, ft/sec	h, feet
0.0	0.00	0.00
0.2	6.44	0.64
0.4	12.88	2.58
0.6	19.32	5.80
0.8	25.76	10.30
1.0	32.20	16.10
1.2	38.64	23.18
1.4	45.08	31.56
1.6	51.52	41.22
1.8	57.96	52.16
2.0	64.40	64.40
2.2	70.84	77.92
2.4	77.28	92.74
2.6	83.72	108.84
2.8	90.16	126.22
3.0	96.60	144.90

$g = 32.20$

A more convenient form for representing the setup of Figure 26 is shown in Figure 28. The horizontal lines are the quantity representation shafts and the vertical lines indicate the interconnections. In the symbol for an integrator, the left arrow is the wheel output, the center arrow is the disk input, and the right arrow is the wheel (radius of action) input.

As another example of the use of the MIT II, consider the problem of determining the response of a series RLC electric circuit to a varying impressed voltage $E(t)$. This problem can be solved analytically if $E(t)$ has certain properties. On the other hand, the properties may be such that an analytic solution is impossible, very difficult, or very unwieldy. The MIT II can, however, readily find many solutions which are not feasible without it or equivalent means. The problem is depicted in Figure 29 where the equation is given in terms of electric quantity q, the coulombs of charge on C. The time rate of change of q is dq/dt and this is the current i in the circuit. The second derivative of q is d^2q/dt^2 and this is the time rate of change of current i, that is, di/dt. The voltage across C depends on q, that across R depends on $i = dq/dt$, and that across L depends on $di/dt = d^2q/dt^2$.

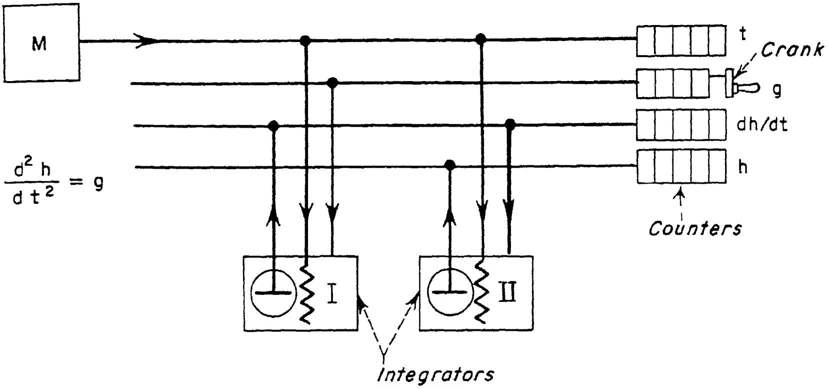
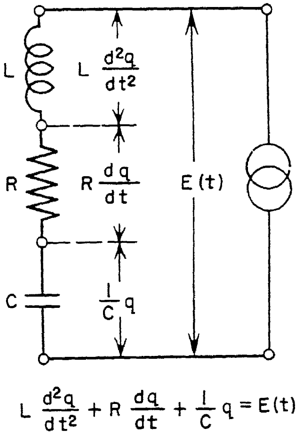


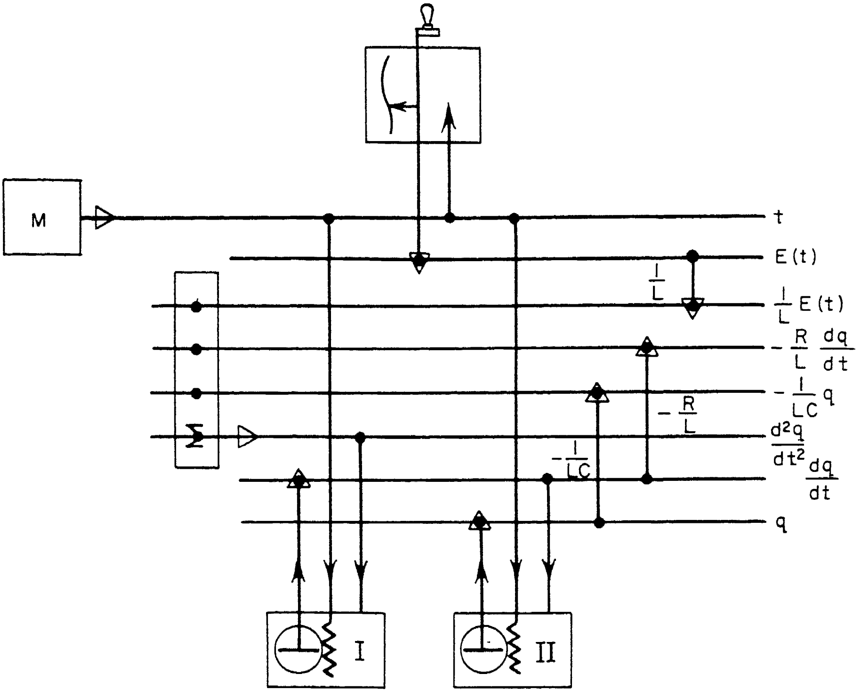
Figure 28.



$$L\frac{d^2q}{dt^2} + R\frac{dq}{dt} + \frac{1}{C}q = E(t)$$

Figure 29.

The setup for the problem of Figure 29 is indicated in Figure 30 where two new symbols are used and the counters are omitted. The symbol at the top represents a *manual function unit.* This unit is a semi-automatic graphic device for furnishing the values of a plotted function corresponding to the values of its argument. As here used, the voltage E as a function of t has been plotted as a curve on the cylindrical surface of a drum. The drum is automatically rotated for t while an operator turns a crank. The crank causes an index to move axially along the drum surface so as to follow the curve. The turning of the operator's crank therefore furnishes a rotational out-



$$\frac{d^2q}{dt^2} = \frac{1}{L}E(t) - \frac{R}{L}\frac{dq}{dt} - \frac{1}{LC}q$$

Figure 30.

put representing *E*. At the left of Figure 30 the vertical symbol represents an adding unit as described on page 117.

Two features of Figure 30 should be noted. One is that the set-up, unlike that of Figure 28, presents a closed loop. That is to say, the d^2q/dt^2 input to integrator I is computed from values of dq/dt and q which depend in turn, one directly and the other via integrator II, upon the output of integrator I. This appears to be a vicious circle but in reality is not. It is not, because initial values of all the terms are part of the problem data, and the solution is started with these values. The machine then keeps track of the changing of the variables and so never has to face up to the seeming paradox of needing to know an answer before undertaking to find it. (Cf. Section III:7). The second feature of Figure 30 to be noted is the small triangles on the quantity representation shafts. There is one for each shaft to indicate the point at which torque is applied to it. This is done to emphasize the fact that a shaft can be driven by only one source, a principle known as the *rule of torques*. The rule seems obvious, but in complicated setups it needs to be remembered. Compliance with it has on occasions called forth considerable artifice to achieve the arrangement desired.

With the setup of Figure 30 properly made, solutions of the equation of Figure 29 can be run off one at a time. Commonly, initial values of q and $i = dq/dt$ would be selected for a run and the function unit would be set to the starting value of $E(t)$. In setting q, dq/dt, and $E(t)$ to their initial values, the mechanism would, operating through the established connections, set d^2q/dt^2. Alternatively, d^2q/dt^2 can be set at its hand-computed initial value before the connections are completed. Thus, with dq/dt and d^2q/dt^2 both set, the two integrators are ready to commence operation. In setting the q shaft, the $-q/LC$ shaft is, of course, set to correspond, and similarly for the $-R/L \cdot dq/dt$ and $E(t)/L$ shafts. The t counter is set to zero and the motor is started. As the motor runs (with an operator following the $E(t)$ curve), the machine generates a continuously varying set of values as required by the setup. These values necessarily satisfy the equation of the problem (assuming perfect mechanism). The run can continue until the required data are obtained or until some mechanical limitation is reached, such as an integrator wheel arriving at the outer usable radius of its disk. The results of the run can be recorded numerically or graphically as in the case of the previous problem.

The MIT II can, of course, handle much more complicated problems than these two simple examples. The solutions can have great importance both theoretically and practically. There are more modes of operation than have been presented, but discussion of them would lie more in the realm of mathematics than of machine characteristics. As a single instance, it may be mentioned that the integrators can be so connected as to perform direct integration (as described), "inverse" integration (the integration of the reciprocal of a quantity), or differentiation (subject to certain qualifications).

In planning a setup, a very important consideration is that of "scale factors".[6] Scale factors are the measures of the quantity representations in terms of shaft rotations and linear displacements. For example, in connection with the last problem, dq/dt might be represented on a particular shaft by 100 turns per ampere and on integrator II by a wheel displacement of 2 inches per ampere. Scale factors are selected to satisfy two requirements. One is to introduce the constants of the problem, such as the coefficient $1/L$ used with $E(t)$ to form $E(t)/L$. The other is to use an optimum scale of representation. This optimum, for shaft rotation for example, lies between very few turns per unit quantity and very many. Very few turns means low precision, but very many turns tends to mean a long solution time. Between lies an optimum, or more properly a compromise, which may be estimated or determined by trial and error. Very few turns per unit quantity is analogous to using a small meter with a crowded scale, while many turns corresponds to a large meter with an open scale. Very many turns per unit quantity means that each run will take a much longer time. This is so because the shafts and other mechanisms must not be operated so fast as to introduce appreciable inertia effects. Such effects would contribute additional errors beyond those already present.

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[6] Caldwell and Bush, *op. cit.*, App. IV, p. 321.

It should be noted that the independent variable t is fed in by the motor and that the motor can be operated at any arbitrary speed within comparatively wide limits. That is to say, the t of the machine is not tied to clock time. It may well progress more slowly or more rapidly than clock time. The t is known as *machine time*. If it is made to follow the clock we say that the machine operates in *real time*. MIT II will seldom operate in real time, but there are comparable machines which do.

As mentioned previously, the interconnections required to effect a setup are accomplished by an elaborate switching system. This system, which utilizes telephone central switch components extensively, performs its functions digitally and is controlled by a perforated tape known as the A-tape. Another tape, the B-tape, remotely controls the gear shifts mentioned on page 117. These are set in decimal increments. A third tape, the C-tape, remotely sets the integrator radii of action. All these tapes are manually prepared on a special punch in advance. Once ready, they permit relatively fast setting of the machine for a problem. They constitute the principal input to the machine, although manual intervention is possible. The tabulations and curves produced during a run are the principal output.

Monitoring means are largely conventional electromechanical devices such as those for overload, limit stops, loss of synchronism, etc. There are no built-in mathematical checks but they can be programmed in many cases if sufficient units are available. For example, a check can be made by duplicating a sequence of operations in a different order. There are also no branch orders explicitly provided. Such orders enable the machine to develop its own program, a prominent feature of digital machines. However, the structure of the machine is such that branch orders could be provided readily if applicable.

Examples of the essential elements as incorporated in MIT II are as follows. Quantity representation for problem variables is primarily by the angular position of a shaft and its electrical equivalent, the angle indicator signals. Quantity representation for logical functions is largely by relay position, operated or not-operated. The external links are principally the A, B, and C tapes for input, and automatic typewriters and graphic plotters for output. Storage of transient data may be regarded as lying in the shaft positions. Retentive storage exists in the graphic devices for data and in locked-up relay configurations for logic. Operations are performed principally by the integrators, adders, and function units. Transfer elements are mostly electrical; angle indicator signal channels for data, and relay control channels for logic. Control is effected through the perforated tapes, A for program, and B and C for data. Power is supplied by independent-variable motors. Three are provided to permit simultaneous operation of the installation in separate parts. Power is also supplied by servo motors, and by conventional power supplies for the relays, electronics, etc.

The MIT II incorporates a great many features which are outstanding examples of design ingenuity and engineering skill. These features were provided to insure overall accuracy (sometimes better than 1 part in 10,000) and flexibility. The details of these features, however, are many. An understanding of them is not necessary to an understanding of the essentially simple nature of the machine. The basic units are the integrators and the adders. These are fundamentally simple mechanisms. The added details come from engineering necessities, and not from theoretical requirements. Even the function units may be omitted in a broad consideration of the machine. This is so because a great many classical functions, such as sin x, log x, x^2, etc., can be generated as needed by integrators and adders.[7]

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[7] Caldwell and Bush, *op. cit.*, App. I, p. 313.

Viewed broadly, then, the MIT II, relying mainly on the essentially simple integrating and adding mechanisms suitably connected, can find solutions to almost any ordinary differential equation of interest. A vast majority of these equations which MIT II can handle so readily, cannot be solved by classical methods, or can be solved only with great labor. In short, what was analytically difficult or impossible, is mechanically easy.

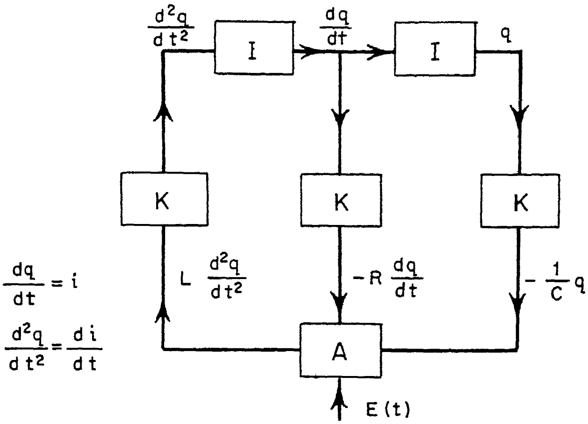
The simple mechanical processes of integration, addition, and so forth, are however, barring mechanical imperfections, exact analogs of their mathematical prototypes. Hence, in understanding the basic nature of these mechanical processes, one understands what is being done in the mathematical processes. Here there is no mathematical symbology to confuse the uninitiated. In a few words, the mechanical analogs are a ready path to comprehending the essence of mathematics.

Electronic Differential Analyzers

Considerable numbers of electronic differential analyzers are in use by educational, scientific, industrial, and Governmental institutions. Varieties of them are available from manufacturers, either self-contained or in component units. Like the mechanical version, basic dependence is upon means for integration and for addition. These means are essentially those shown in Figures 18 and 9, but the circuits are usually more sophisticated in order to obtain better performance. However, an overall accuracy of 1 part in 100 is attained only with difficulty, as compared to that of the MIT II which often exceeds 1 part in 10,000.

As an example of an electronic differential analyzer, consider again the problem depicted in Figure 29. Here an inductance L, a resistance R, and a capacity C are connected in series and are subjected to a voltage E. The voltage E varies with time t in a manner to be discussed later. What we wish to find out is the way the voltage across C and the current through R vary as functions of time. We could find out other things as well, but these two will suffice as examples.

There is more than one way to set up this problem. One way is indicated in Figure 31, where six units are used. Two are integrators I, like the one in Figure 18. One is an adder A, like the one in Figure 9. The remaining three, denoted by K, are simple amplifiers. Each K amplifier can have its gain manually adjusted so that its



$$L\frac{d^2q}{dt^2} = E(t) - R\frac{dq}{dt} - \frac{1}{C}q$$

Figure 31.

output equals its input multiplied by a constant factor. The value of the constant factor may be less than, or greater than, one, depending upon the gain set. The factor may also be positive or negative depending upon the terminals connected up, as these units usually provide both positive and negative output terminals. Other units will be required to complete the setup but they are not indicated in the figure as they are not essential to the description.

The left I-unit receives a voltage input which represents d^2q/dt^2 to the chosen scale. It integrates this input and delivers as output a voltage representing dq/dt. This output becomes the input for the right I-unit. The second I-unit delivers q as an output. Both integrations are performed with respect to t, of course. This t is an actual t, a clock t, so to speak. The actual t can, however, when required represent a fictitious problem time T by the use of suitable scaling factors. (Cf. p. 123).

The initial values of dq/dt and q may be zero or otherwise, depending upon the chosen problem. These values are set into the left and right I-units, respectively. Each is set by charging the integrating capacitor C (Figure 18) to a voltage which represents the initial value to scale. The setting is done by switching C to a properly preset constant voltage source (a potentiometer across a regulated power supply). Capacitor C is first switched to the setting voltage before the problem run begins, and is returned to its integrating circuit at the instant the run starts.

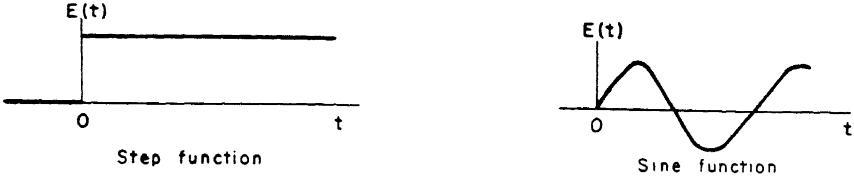
The dq/dt and q integrator outputs are led through K-units where they are multiplied to scale by $-R$ and $-1/C$, respectively. These values of R and $1/C$ are hand-set on the K-units according to the problem values, and the minus signs are supplied by making the connections to the negative terminals.

The outputs of the right K-units are inputs to the A-unit. Another input is the driving voltage $E(t)$. These three inputs are summed and become the A-unit output, $-Rdq/dt-(1/C)q+E(t)$. This output is the right side of the equation written under Figure 31. Hence, it is also Ld^2q/dt^2, due to the equation. On dividing it by L in the left K-unit, it becomes d^2q/dt^2, and is the input to the left I-unit.

The six functional units, when connected as shown, mechanize the equation of our sample problem. That is to say, the assembly of units and connections when properly operated must perform in accordance with the equation. With due regard to unit limitations, and using suitable scaling factors, we can choose many combinations of problem values. For each combination the machine will tell us how our RLC circuit will respond to the driving voltage. The values we will select will be those for R, L, C and the initial current $i = dq/dt$ and the initial charge q. The answers we require are the ways i and q/C vary with time. These answers are found in the outputs of the left I-unit and the right K-unit, respectively. Others can be had if desired.

The behavior of the RLC circuit, or more properly that of our analog setup, will depend upon the character of $E(t)$ as well as upon other things. Most of these other things, such as the values of initial i and q, we have considered already. Now we will consider $E(t)$ briefly. It may have many forms, but two are of especial interest. One of these important forms is the step function and the other is the sine function. Both are depicted in Figure 32.

The *step function* in our context usually means a function which is zero up to time zero and then instantly becomes a positive con-



Step function

Sine function

Figure 32.

stant for all the remaining solution time of a problem. We do not need to consider other meanings here. Physically, this means that a constant voltage is instantly applied at the beginning of a solution run. The virtue of this function is that it represents the sudden initiation of action, such as the rapid closing of a switch in our example. It causes the system under study (our RLC circuit) to exhibit its transient response. This transient response, or reaction to sudden impetus, may be important in itself if the system is to undergo such treatment. But even more important is other information on system performance which can be derived from the transient response by suitable analysis. The details of such analyses are beyond the scope of this book. Suffice it to say they are a valuable technique.

The *sine (cosine) function* is, of course, the simplest wave shape. It may or may not start from zero as shown in Figure 32. Its amplitude, or peak value, and its frequency, will depend upon the individual problem. A sine function voltage is the idealized form of most AC and the output of most electronic oscillators. However, for computer purposes, socket power is a fixed frequency and is not sufficiently pure sine, so the function must be specially provided. The sine function represents the driving power of many electric devices. It also causes a system to exhibit its steady state response. This response is like the transient one, capable of yielding much useful information on system performance.

In our sample problem, the variations of i and q/C during a run can be displayed graphically. If the solution is obtained relatively slowly, say in a minute, the graphic device may be an electromechanical plotter. This will give a permanent record. On the other hand, if the solution is obtained relatively fast and repetitively, say 20 times per second, the graphic device may be a cathode-ray oscilloscope (similar to a TV presentation). Here a permanent record can be made by photographing the display. Either the plotter or the oscilloscope is designed to receive the i and q/C voltages from our setup and form the desired curves.

Other problems may require more units and other kinds of units than those indicated in Figure 31. Some of the possibilities were discussed in Section III:5 and many more can be found in manufacturers' catalogs.

There are two divisions of electronic differential analyzers according to speed of operation. There are relatively slow machines whose solution times are in the order of minutes, and there are relatively fast ones which obtain many solutions in a second. The operating speeds of both types can be varied and at times there may be an overlap. The slow machines can utilize such electromechanical devices as resolvers (p. 101) and servo-operated potentiometers (p. 101) or function generators (p. 109). They tend to be more accurate, but this is a moot question. The fast machines with oscilloscopic display facilitate the "dynamic" (or rapidly responsive) study of a system by quick visible compliance with manual variations of parameters. A combined use can be very effective. Here exploratory work is first done on a fast setup and then more painstaking values are obtained on a slow one. Either machine can be used in real-time system analysis or simulation depending upon the speed of the system studied or simulated.

The programming of this type of computer is largely a matter of manual plug-and-jack cabling and dial setting. The operation is facilitated sometimes by separable jack panels. These panels can be plugged up with patch cords away from the computer. This saves tying up the computer during cabling. Moreover, spare panels permit retention of useful patterns. However, there are still many dial settings to be made, and other preparations to be carried out, at the computer, before a run can be made. In short, programming an electronic differential analyzer is still a rudimentary operation. It has not been mechanized to the extent that it has been for MIT II, to say nothing of digital computers.

The essential computer elements are exemplified in these machines in several forms. Principal among them are the following. Quantity representation is largely by voltage. External links for input are mostly cabling for logic and dial setting for data. Output links are notably the graphic presentations. Storage is represented by the set positions of potentiometers and the transient charges in capacitors. Operations are performed mostly by amplifiers and servo units. Transfer is almost entirely by electric wiring. Control was discussed in the paragraph above. Power supplies are conventional.

Perhaps the greatest advantage of electronic differential analyzers is that they tend to be relatively cheap and plentiful. They can be assembled largely from the mass-produced components of the radio and TV market without special machinery or highly skilled operators. They can be as simple or as elaborate as circumstances require. They can often be made available for use by the project engineer who is not a trained computer man.

Electronic differential analyzers can solve practically any ordinary differential equations of interest. So far they have not been systematically applied to partial differential equations, although this is possible. They can be used on abstract problems or in practical design and test work. A setup can be used to simulate a part or the whole of a physical system. For example, in testing a missile guidance system, a computer setup can simulate the flight characteristics of the missile. The guidance system will give its commands to the analog missile and the analog missile will report back to the guidance system what it is doing and metering.

Other Computers

Differential analyzers have received major attention here because they are an outstanding class of computer, both as to numbers in use and as to potency. However, there are many other types of analog computers, and we shall now consider a few of them.

Many ingenious computers of limited applicability have been constructed in laboratories on a one-of-a-kind basis. Their builders have utilized optical, photoelectric, thermodynamic, and other principles to analog the equations of interest. Descriptions of such devices can be found in the scientific journals.

A number of devices known as "network analyzers" have been built in educational and industrial laboratories. These devices are principally groups of such electrical entities as resistors, capacitors, inductors, power sources, and meters. They are so disposed that they can be readily switched or cabled into configurations to simulate complex circuits. The distributed constants (resistance, capacity, etc.) of long lines (such as for high-line power transmission) can be imitated by their lumped-constant equivalents. The various circuit assemblies can then furnish, within the confines of the laboratory, an analog of a network which may extend over many miles. The analog can be studied by well-known electrical techniques to determine the characteristics of the full-scale network. These analyzers also find extensive use in the analog study of airframes and related problems.

Another type of computer, usually termed an *algebraic equation solver,* is commercially available. It makes use of simple electrical principles to find solutions to sets of simultaneous linear algebraic equations such as:

$$a_1x + b_1y + c_1z = d_1$$

$$a_2x + b_2y + c_2z = d_2$$

$$a_3x + b_3y + c_3z = d_3$$

One make of machine can handle up to 12 equations in 12 unknowns. Its basic mechanisms are potentiometers (Figure 13), switches, and a sensitive null indicator (a device to indicate that two opposing voltages are equal). The operator adjusts the potentiometers successively, comparing their settings to a precision four-dial resistance decade (switchable resistors arranged and valued by powers of 10). When a solution is obtained, a matter of several minutes, the values of the unknowns (*x, y, z,* etc.) are represented by potentiometer settings.

An Harmonic Analyzer

There are several forms of harmonic analyzers. Such a device is designed to evaluate the amplitude (peak value), and possibly other information, of the "harmonics" of a function containing many harmonics. A ready example is a musical note which is made up of the simultaneous sounding of a number of pure tones. The pure tone of lowest frequency (say 100 cycles per second) is known as the fundamental or first harmonic. The second harmonic will have a frequency twice as great (200 c.p.s.). The frequency of the third harmonic will be 300 c.p.s.; and so on. The relative amplitudes (strengths) of the harmonics will determine the character of the note, and their absolute amplitudes will determine its loudness. Other phenomena besides musical notes can be considered as made up of harmonics and a knowledge of the harmonics can be of great value. These facts are comprised in *Fourier Analysis,* for the meaning of which the reader is referred to mathematical textbooks. For present purposes we shall merely outline one form of machine for measuring the harmonics of a curve. This curve is supposed to have been plotted on paper so as to graphically display the function to be analyzed.

The first harmonic analyzer was invented by Lord Kelvin in 1876 following the invention in the same year of an integrating mechanism by his brother James Thomson.[8] It provides for obtaining eleven harmonics simultaneously. However, as the principles are the same for all harmonics, we shall describe only one with the help of Figure 33.

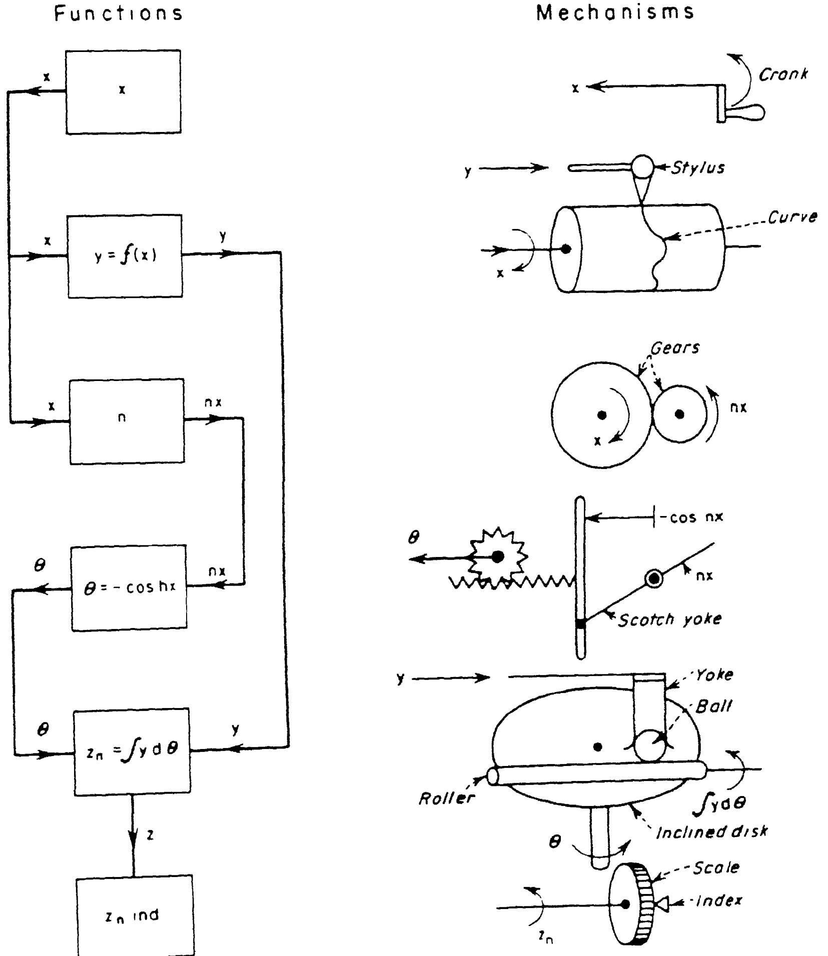


Figure 33. Harmonic analyzer.

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[8] For a description and a picture of the complete device, see Baxendall, D. / "Mathematical Instruments" in "Encyclopedia Britannica", 14th edition, vol. 15, pp 69-71.

In Figure 33 are shown in parallel columns the functions to be performed, with their connections, and the mechanisms for performing them. The problem to be solved by this unit of the analyzer is to obtain z_n for a particular value of n in the formula:

$$z_n = \int_0^{\pi} f(x) \sin nx \cdot dx$$

Here z_n represents (with certain constants unitized) the value of the nth harmonic of the function $f(x)$ which is to be analyzed in the range 0 to π (other ranges and the cosine function can be used as mentioned below).

At the top of Figure 33 is indicated the independent variable drive for x. It is powered by a hand crank. The x drive operates one dimension (rotation) of the $y = f(x)$ mechanism. This mechanism is principally a cylinder around which the given function $f(x)$ has been wrapped after plotting on paper to the scale of the device. The circumference of the cylinder is considered to range from $x = 0$ to $x = \pi$. A stylus is manually caused to follow the curve of $f(x)$ as the cylinder is rotated by the x drive. The translation of the stylus then represents y. The x drive also operates a gear pair such that the driven gear turns n times as fast as the driving gear. Thus the n mechanism has a rotational input of x and a rotational output of nx.

The nx drive rotates the crank of a Scotch-yoke and rack-and-pinion mechanism. The motion of the crank causes the yoke to move according to $\cos nx$. The motion of the yoke, in turn, by means of the rack, causes the pinion to rotate so that $\theta = -\cos nx$. The *rate* of turning of the pinion at any instant is the derivative, i.e., $d\theta/dx = n \sin nx$.

The fifth unit in Figure 33 is the Thomson integrator. An inclined disk is rotated for the variable of integration, θ in this case. Resting on the disk is a ball which also rests against a roller. The roller is so placed that the ball always contacts the disk along a line. This line passes through the center of the disk, and the weight of the ball holds it against both roller and disk. The ball can thus transmit motion from the disk to the roller. The distance of the ball from the center of the disk is controlled by a yoke. As the yoke moves the ball farther and farther from the center of the disk, the roller is caused to rotate more and more for the same rotation of the disk. In other words, with y being the disk radius at which the ball is held by the yoke, the roller turns at a rate of $dz = y d\theta$, and the total rotation z of the roller represents $\int y d\theta$. The total rotation z of the roller is indicated (z ind.) by means of a visually read scale mounted on the roller shaft and a fixed index mark mounted on the frame of the device.

It was noted above that $d\theta/dx = n \sin nx$ and that $y = f(x)$, hence with the connections shown in the figure:

$$dz = y d\theta = nf(x) \sin nx \cdot dx$$

and

$$z_n = n \int f(x) \sin nx \cdot dx$$

We absorb the coefficient n before the integral sign into the other scale factors which we have considered unitized. When we operate the device through the range 0 to π, we have the desired result:

$$z_n = \int_0^{\pi} f(x) \sin nx \cdot dx$$

In the Kelvin machine, only one $y = f(x)$ cylinder-and-stylus mechanism is needed. The stylus motion moves the yokes of all eleven integrator balls together. This is an example of how special purpose combinations permit simplifications of mechanisms (but, of course, restrict versatility).

The cosine rather than the sine integration can be performed, depending only upon the starting positions of the Scotch yoke devices. Higher components than the eleventh can be evaluated, at least in theory, by having the curve for $y = f(x)$ make more than one turn around the cylinder. If there are m loops of the curve around the cylinder, the integrator which evaluated component n for a single loop will now evaluate the component mn.

An Harmonic Synthesizer

This device is the reverse of the harmonic analyzer. The problem now is to plot a compound function when we are given its harmonics (harmonic components). In this case we shall include *phase angles* which we did not discuss in connection with the analyzer. A phase angle takes account of the fact that in certain cases it is useful to consider the components as starting from different points along the x axis. Its precise meaning should be clear from the mechanism.

An early form of harmonic synthesizer which has found practical applications is shown schematically in Figures 34 and 35. This

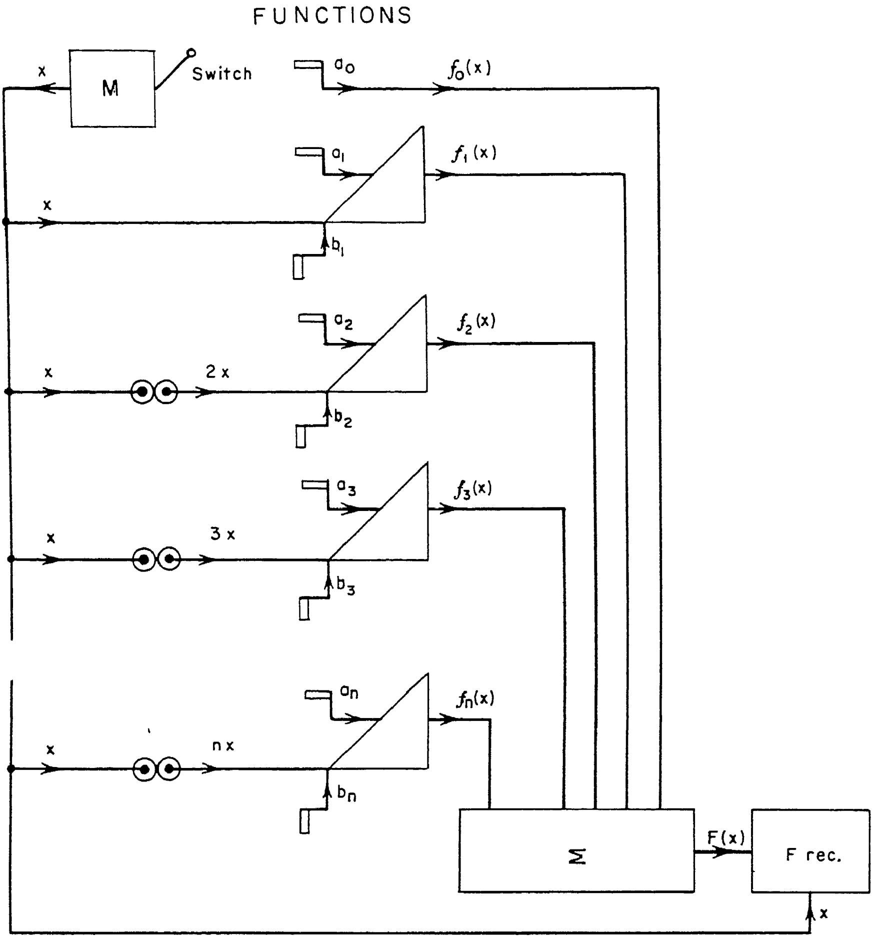

Figure 34. Harmonic synthesizer.

form of the device has been used successfully for years to predict tides and tidal currents. The harmonic components are known from the gravitational effects the moon, sun, and planets have on the seas, and measurements made at selected coastal points by tidal gauges. These data are expressed as amplitudes and phase angles of Fourier series and the series are evaluated so as to yield predicted values of tidal heights and currents for a year or more ahead.[9]

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[9] Baxendall, *loc. cit.*

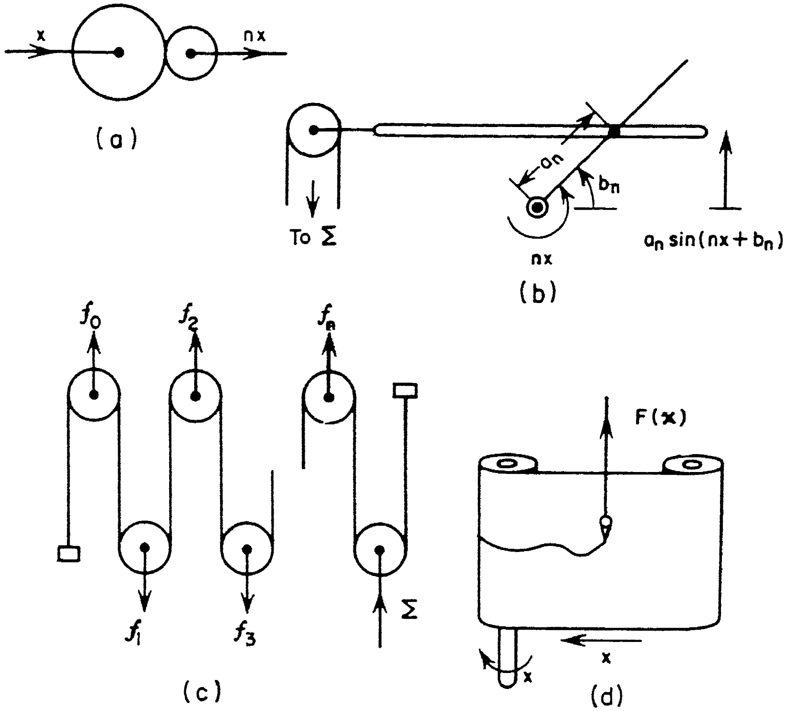

Mechanisms

Figure 35. Harmonic synthesizer.

The problem may be expressed formally as to plot $F(x)$ given:

$$F(x) = f_0(x) + f_1(x) + f_2(x) + f_3(x) + \ldots\ldots f_n(x)$$

where

$$f_0(x) = a_0$$

$$f_1(x) = a_1 \sin(x + b_1)$$

$$f_2(x) = a_2 \sin(2x + b_2)$$

$$f_3(x) = a_3 \sin(3x + b_3)$$

$$\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots$$

$$f_n(x) = a_n \sin(nx + b_n)$$

The a's are the amplitudes of the components and the b's are their phase angles.

Figure 34 shows the functional arrangement. The main drive (M) is an electric motor which powers the independent variable x. By means of shafting, x is transferred to each component section except the zeroth which is a constant term. At each succeeding section after the first there is a gear-pair (or equivalent) which increases the driving rate by an integral ratio, i.e., the sections are driven for x, 2x, 3x, ... *nx*. The gear pairs are depicted at (a) of Figure 35.

In each component section of Figure 34 except the zeroth there is a variable crank or Scotch yoke mechanism. This is shown in more detail at (b) of Figure 35. The effective length of the crank is, according to scale, equal to the amplitude of its component, i.e., to its *a*. The *initial* angular setting of the crank is its phase angle, *b*. Each crank is turned according to *x*, 2*x*, 3*x*, ..., *nx* as appropriate.

The slot which is positioned by the crank pin moves parallel to itself. It is displaced from the crank center by a distance which represents to scale the instantaneous value of the component; for example, a_n sin $(nx + b_n)$ as shown in Figure 35(b). The slot carries with it a pulley which is equally displaced. Riding on this pulley is a chain by which the motion of the pulley is communicated to the summing section denoted by Σ.

The summing section is principally the chain which passes over the several component pulleys and is fixed at both ends. One additional pulley is shown marked Σ in Figure 35(c). This extra pulley is moved by the chain (with a spring or weight, not shown, to prevent slack) and its motion represents the sum of all the other motions (p. 95). As the other motions represent f_0, f_1, ..., f_n, the Σ motion represents *F(x)*.

Finally, the *F*(x) motion is recorded against x on a chart driven by the x drive. As indicated in Figure 35(d), the *F*(x) motion moves a pen vertically while the chart moves horizontally and a curve is traced.

The foregoing synthesizer is a veteran of many years. It deals with functions of only one independent variable, *x*. A modern successor, known as X-RAC (for X-ray Analog Computer), has been built at Pennsylvania State University. Invented by Dr. Ray Pepinsky, it uses electronic techniques (more than 4000 tubes) to correlate X-ray diffraction data and present two-dimensional syntheses of crystallographic patterns on an oscilloscope. An explanation of these terms will not be offered. All that is intended is to indicate that harmonic synthesis can have modern utility and expression.

Models

It is perhaps stretching a point to include models within the term computers, but they do serve the same purposes and use the same general principles as more sophisticated computers. So, while we may seldom refer to a model explicitly as a computer, it is well to bear in mind its properties as such. If it is to perform its purpose it must provide the essential computer elements, however unobvious they may be.

Examples of models are:

- Stress-strain configurations, such as plastic shapes (representing structural members) which are stressed appropriately and their strains observed optically;
- Aerodynamic models which are tested in wind tunnels and ship models which are tested in model basins;
- Hydraulic models which may be simple configurations of piping, valving, etc., or elaborate facsimiles of rivers and harbors where flow, erosion, tidal, and other effects are studied;
- Machinery models such as small-scale replicas of engines, pumps, etc.;
- Electrical models (cf. p. 131).

Models are usually constructed on a much smaller scale than the prototype they represent. They may, however, be full-scale or even much larger than their analogs. Scaling up is usual when the prototype is very minute. Two extrèmes of scaling are, on the one hand, a mechanical model of the solar system, and on the other, the chemist's rod-and-ball model of a molecule.

It is usually necessary to know or assume appropriate laws of similitude in order to interpret the relations between a scale model and its full-size prototype. It is also necessary to know or allow for the effects of a model's departures from strict similitude as to dimensions, materials, or modes of operation, for a model will rarely be a true analog in every respect.

As a specific example, consider an airfoil undergoing test in a wind tunnel. While the airfoil itself is termed a model, the wind tunnel and its appurtenances form a part of the model situation.

The airfoil will be suitably suspended in the wind stream so that its location and attitude can be controlled and measured. There will be pickups to permit the measurement of desired thrusts, torques, pressures, temperatures, and velocities. The configuration of the air flow in the neighborhood of the airfoil may be observed and recorded. This may be done by using smoke trails or by the Schlieren technique, an optical system which utilizes the variations in the refractivity of air due to variations in density to form images of wave fronts.

For a given wind tunnel and airfoil model, the inputs of principal interest will be airfoil attitude and the air stream velocity, pressure, and temperature (perhaps as spatial distributions). The outputs, i.e., the results which the setup "computes," will include thrusts, torques, pressure distribution along the airfoil, and air-stream patterns as evidenced by streamlines and standing waves. These "computations," if attempted by conventional mathematical methods, are for the most part exceedingly complex and so lengthy as to tax even the most advanced electronic digital computers. Conventional mathematics can, in fact, deal with such computations only after simplifying assumptions have been introduced, and must look to the analog (model) results for confirmation. The model technique itself is not free of assumptions, as was mentioned earlier, but it is much more nearly so than are strictly analytic methods. This closeness of model procedures to physical fact will insure their continued use even when the more abstract computers become highly sophisticated. Moreover, for many purposes, models are simpler, quicker, and cheaper.

III:7 FUNCTIONAL CONSIDERATIONS

Equation Formulation

In designing or programming a computer, perhaps the first theoretical consideration is the form in which the equations are cast. Mathematical manipulations will often permit recasting the equations from the form in which they originally arise to another better adapted to mechanization and to the particular objective. There will usually be a number of alternatives available, and it will rest with the designer or the programmer to select those most likely to facilitate successful operation within the overall requirements. Conversely, it is possible that a poor choice or formulation of the problem may make its mechanization unduly complex, inaccurate, costly, or otherwise unacceptable. For example, an ill-adapted coordinate system may be selected when the problem is inherently simpler in a particular reference set. Such a case would arise if a problem which is inherently polar were mechanized in rectangular coordinates, or vice versa.

It is particularly advisable to avoid problem formulations which require operations that are difficult or costly to implement. Differentiation is an example. While it is analytically easier than integration, the reverse is true mechanistically. Mechanical and electronic differentiators are available, but their performance is marginal. They are especially troublesome when "noise" or discontinuities are involved. On the other hand, integrators perform very satisfactorily. Hence, an integral formulation of a problem is much to be preferred to one which is differential. Integral formulations, fortunately, are usually feasible.

Somewhat similar considerations apply to multiplication or division. The units for these operations tend to be complicated and costly. These operations can sometimes be avoided by suitable formulation. For example, use can perhaps be made of inverse integration (p. 123) or of the relation well-known in calculus that $UV = \int UdV + \int VdU$.

Balanced Design

The overall design of a computer should be balanced in several respects. Such things as resolution, accuracy, and operating speed should be maintained at about the same level throughout the machine. This principle seems obvious, but it has sometimes been overlooked. An outstanding example of the results of not conforming to it was presented by the earlier digital electronic machines. In these machines there was a very great mismatch between their high internal operating speeds and the effective speeds of their external links. The machines could process data on the inside far faster than the data could be supplied from the outside, or the answers could be returned to the outside. Similar remarks would apply to MIT I, for "getting on and off" the machine frequently consumed days, as compared to a few minutes of problem running time. This unbalance between setup and running times was one of the reasons for undertaking MIT II.

The operating speeds of internal elements should also be balanced among themselves in so far as practicable. In other words, bottleneck and runaway units should be equally avoided. There should likewise be a substantial balance among units as to resolution and accuracy. An operation to 1 part in 10,000 by one unit is a needless refinement if the result is then subjected to another unit which is good only to 1 part in 100. Conversely, if most units are capable of the higher resolution or accuracy, it should not be thrown away by one or two units of much lower capabilities. More is said on this topic in Section III:8. The whole question of balance, as to speed, accuracy, or otherwise, may be viewed as akin to the electrical principle of matched impedances. This principle and its applications are thoroughly discussed in electrical textbooks.

Simplifying Techniques

A program technique of possible utility arises when we consider scale factors and levels. The procedure is to deal with incremental variations rather than with the variations of a whole quantity. This is sometimes referred to as *suppressed zero*. For example, in dealing with a spring which changes length by 10 percent during the course of a problem, we may be able to handle the changes alone as a variable in the computation rather than the entire spring length. If our computing accuracy is 1 percent, then we are dealing with 1 percent of 10 percent rather than with 1 percent of 110 percent, an improvement factor of 11.

The foregoing technique may be considered as a special case of the use of the method of differential variations. In this method the equations are subjected to mathematical differentiation to yield expressions for the changes in results due to small variations in the variables. In many cases these expressions can be more readily utilized than can the principal equations. We may be content to know the effects of small variations only, and the new equations will give them. However, if solutions of the principal equations at suitable intervals are otherwise available, the intervals can be bridged by the differential variations. This bridging will then give continuous answers to the original problem. An example is to be found in the preparation of missile firing tables. Here the effects of small changes in firing conditions from those considered standard are evaluated by means of differential variations. When these effects are applied to the standard tabulations we have specific firing data.

A technique which is virtually the reverse of the preceding one is that of *series expansion.* In this case an expression to be mechanized may be represented adequately by two or three terms of its mathematical expansion into a series. These terms may be much simpler to mechanize than the full expression. For example, in a particular case it may suffice to use $1 + x$ for $1/(1 - x)$ or for e^x, these being the first terms in their series expansion. Thus, in using a series expansion, one may in effect concentrate on the large change and ignore the finer portion, while in using differential variations, the large change is set aside and the finer changes are emphasized.

Another technique which may be required is *interpolation* and its extension, *extrapolation.* Interpolation arises when it is necessary to have intermediate values of a function which of necessity or for convenience is available only for discrete values of the arguments. There are numerous ways in which interpolation can be effected. We may use mechanized mathematical formulas or depend primarily upon mechanical effects. An example of the one is to mechanize the formulas for interpolation by one of the methods of differences. An example of the other is to depend upon a curve or cam which has been faired through the given points.

A very important technique is *linearization.* This means substituting a linear approximation (such as x) for a nonlinear formula (such as x^2) over a limited range. In the limited range, the difference between the approximation and the correct formula should be negligible. It may be necessary to linearize in order to fulfill the overall objectives of the computer, or to simplify and improve its design, fabrication, or use. Linear expressions will often be easier to mechanize and will usually yield more readily to theoretical analysis. Such expressions are frequently obtained by the method given in the second paragraph above.

Implicit Functions

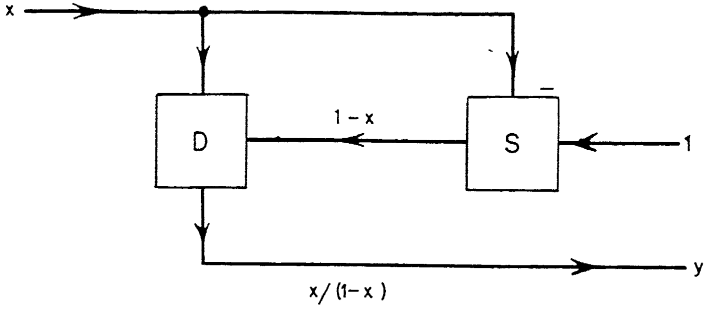
This is an extremely powerful technique. By using it we can often solve problems by indirection when a direct solution would be more complicated or difficult or even impossible.

We speak of explicit functions when they are directly expressed and of implicit functions when they are only implied. When we write $y = f(x)$ we denote that y is some expressed function of x. For example, $y = x/(1 - x)$ is an explicit function, for it tells us just how y depends upon x. On the other hand, if we write $f(x,y) = 0$ we are denoting an implicit function, for the dependence of y upon x is not explicitly stated. For instance, $x + xy - y = 0$ is an implicit functional relation of x and y. This relation happens to be the same as that of our previous example. Now it is implied only and not directly expressed. To get the explicit function from the implicit one, it is necessary to solve for y in terms of x. This is the crux of the matter, for it is easy to *say* solve, but not always easy to do it. It was easy to do in our simple example. It was no trouble to turn $x + xy - y = 0$ into $y = x/(1 - x)$. But there are many, many cases where the solving is difficult, complicated, or impossible.

Fortunately, it is often possible to mechanize a known implicit functional relation without bothering to solve it for the unknown explicit relation. Moreover, it is also frequently simpler or better to mechanize a function in its implicit form even when its explicit form is easily obtained. When we do this we may, for instance, use a device for multiplication rather than one for division, or a device for integration rather than one for differentiation. We do so usually because multipliers and integrators are better performers than dividers and differentiators. Indeed, there may be no practicable divider or differentiator available for a particular type of computer. (Cf. pp. 104 and 141).

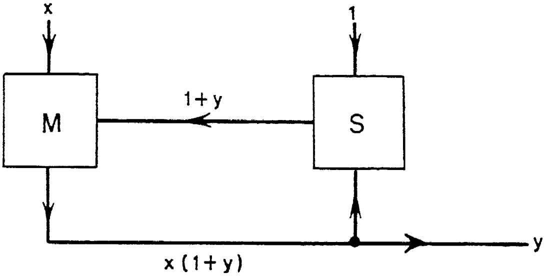
Consider again the example given above. We can mechanize the explicit function $y = x/(1 - x)$ as shown in Figure 36. A divider, D, and a summer (subtractor), S, are connected as shown. To do this requires, of course, that a suitable D unit be available (see p. 104). Another way to mechanize the function is to do so in its implicit form as shown in Figure 37. Here we use an M (multiplier) unit in place of a D unit. Many forms of M units are available, and the setup may be mechanical, electronic, or other. Note that the function is not fully solved for y (i.e., y appears on both sides of the equation) but that nevertheless we get y as an output. This is characteristic of implicit function procedure.

Still another way of mechanizing the same function, again in implicit form, is shown in Figure 38. This way is especially useful



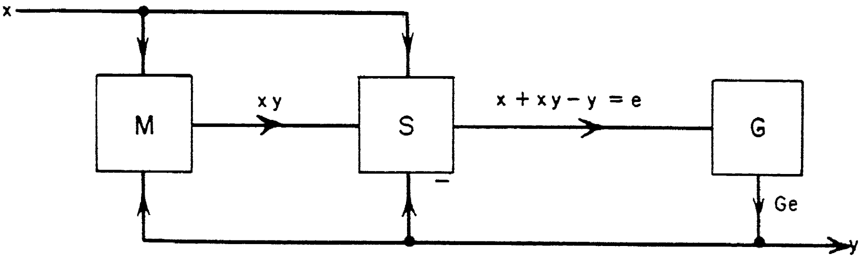
$$y = \frac{x}{1-x}$$

Figure 36.



$$x(1+y) = y$$

Figure 37.



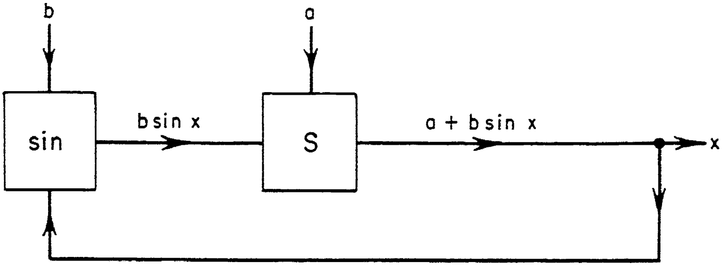
$$x + xy - y = e \doteq 0$$

Figure 38.

in more complicated problems. Here, besides the M and S units of the previous instance, there is a high-gain amplifier, G. The M and S units now must be electronic or be equipped to operate in conjunction with G. The three units are connected as shown and produce y as an output. This output is subject to a small error theoretically. Practically, if the gain of G is sufficiently high, the error is altogether negligible. The error exists because the output of S is not zero, as required by the equation, but e. This e is a minute voltage which is multiplied by the high gain of G to produce Ge. We use Ge as y, that is, to a high approximation, $Ge = y$. Thus, Ge is fed forward as output y, and is fed back as an input to the M and S units. The setup requires that effectively $Ge = y$, or if not, that e change until it does. Note that as y is a quantity of ordinary magnitude, while G is very large, it follows that $e = y/G$ is very small, as we said.

The procedure given in the above paragraph exhibits the use of *feedback*. It is so called because the answer y is fed back for use in finding its own value. The same thing is true of the previous example (p. 144) and of the example discussed on page 122. As pointed out, the seeming paradox of needing to know an answer before you can find it is not real. It does, however, bring up two important considerations. One is, obviously, that a proper solution of the problem must exist, for the machine cannot find a nonexistent solution. This apparently trivial observation involves, however, more mathematical subtleties than we can go into here. The other consideration is that the computer setup must be stable. It must settle on a solution and not go into violent oscillations. Again, this is too extensive a topic for discussion here. It is exhaustively covered in books on servo and amplifier theory. Moreover, the question of stability is frequently resolved, not by analysis, but by trial and error.

A final example may illustrate how much more effective than explicit formulation the implicit can be. The equation is $x = a + b \sin x$, and x is wanted in terms of a, b. This equation is known in astronomy as Kepler's equation for the eccentric anomaly. We are not concerned with its astronomical meaning but with its character. We use it as an example, not because its analog solution would have any practical importance, but because it shows well the difference between explicit and implicit formulation. An explicit solution is given at the bottom of Figure 39. This is an infinite series due to Lagrange. Each following term beyond those given is more complicated than its predecessors. Even those given would require fairly elaborate mechanization. We can contrast this with the very simple mechanization in implicit form as indicated in the figure.



$$x = a + b \sin x$$

$$x = a + b \sin a + \frac{b^2}{2} \sin 2a + \frac{b^3}{8} (3 \sin 3a - \sin a) + \frac{b^4}{6} (2 \sin 4a - \sin 2a) + \cdots$$

Figure 39.

Only two units are required: S for summing, and sin for the sine function (p. 109). A special purpose mechanical computer for this application could be very simple indeed, but its precision would be low by astronomical standards.

Abnormal Operation

Abnormal operation can arise from a number of causes. In general, means should be provided to minimize such occurences, to signalize their advent (in advance if possible), and to take automatic action. Such action should prevent or minimize damage to the problem in work, to the computer, or to the system which the computer is serving. Just what such means will be will depend upon many considerations. Among them are the nature of the computer; the system, if any, with which it is associated; the types of abnormalities which can occur or be anticipated; the devices available and practicable for coping with the abnormalities; and so forth. The commonest class of abnormality in the more complex computers is likely to be physical component failures. These include tube burnouts, stalled motors, and other engineering deficiencies. There are conventional devices to cope with such contingencies (e.g., pilot lights, overload relays, interlocks), and preventive maintenance can greatly reduce their incidence. There may also be operational abnormalities such as program sensitivity. This arises when unit tolerances unexpectedly combine. It may also arise from a short-term history of unit performance, as when a residual capacitor charge has not been adequately erased. Another frequent cause of abnormal operation may be programmer or operator error. Among the methods for reducing such errors are training, standardization, and simplification of procedures. There are also cross-checking and trial runs.

III:8 ERROR CONTROL

Accuracy and Precision

Up to this point we have said very little about accuracy, precision, resolution, reproducibility, and such. We have tacitly assumed that unless a computer has these qualities in sufficient measure it cannot serve its purpose. There is a tendency to use the words accuracy and precision interchangeably. Different writers place different interpretations upon them although there is general agreement as to the concepts they connote. For the purposes of this chapter we will define them by considering a wooden yardstick. Let us suppose that after the stick was printed from a high-grade master the wood shrank so that the whole scale is shortened. We then say that the yardstick is *inaccurate*. On the other hand, consider two yardsticks, one divided no finer than quarter inches and the other divided to thirty-seconds of an inch. We say that the first is not as *precise* as the second. Precise readings to a thirty-second may be inaccurate as a result of the shrunken scale. Conversely, accurate readings with an unshrunken scale may be imprecise because the divisions are made no finer than a quarter inch. The accuracy and precision of a scale should, in general, be within the same range of magnitude. It is obviously absurd to have a scale divided to thousandths if its distortion may introduce errors in the tenths. It is likewise unreasonable to insist upon an accuracy to a thousandth in a scale which is to be used to measure only to tenths.

Similarly, the scales and operations of a computer should have accuracy and precision correlated to those of the data which will be its inputs and outputs.

It is a common fallacy to report 1/100 percent results based on 1 percent information. And it often happens that 1 percent information is degraded by inadequate processing to yield 10 percent results. Mathematics per se cannot add to, and in general should not subtract from, physical information; it can only reorganize it and deduce its consequences. For example, in averaging a number of measurements to find their mean value, which is generally regarded as more reliable than the individual measurements, the mathematical process of averaging contributes no information of itself—it merely extracts the information contained in the measurements themselves. The improved value of the mean does not come from the operations of addition and division, but from the greater number of measurements, i.e., from the greater pains taken in making the overall measurement. This principle, that mathematics of itself does not provide physical information, is often lost sight of in more abstruse cases than mere averaging. Put differently, one may say that the physical world does not conform to mathematical laws; it is rather the mathematical relations which aid in the description of physical laws. It is true that we can sometimes compute values with more confidence than we can measure them, but this is merely using mathematics to invoke more reliable measurements from the background of work by others.

False Accuracy

One should be on guard against an illusory accuracy, i.e. an accuracy which appears to exist but actually does not. An example arose at one time when it was seriously proposed to have an angle-measuring device read to seconds of arc. This was to be done by using a gear train to multiply the principal shaft rotation. The multiplied rotation would drive a counter to indicate seconds. One rotation of the counter digit wheel would then represent 10 seconds, whereas one rotation of the principal shaft would mean 1,296,000 seconds (360 x 60 x 60). Hence a gear stepup of 129,600 to 1 would be needed. The first gear on the principal shaft was to be about 5 inches in diameter. With this diameter a second of arc would mean about 12 microinches of circumferential distance, or 12/1000 of 1/1000 of an inch. To machine gear teeth to such accuracy in a production job is a fantastic proposal. So, while the precision of reading the counter would undoubtedly be one second, the accuracy of reading the angle would certainly be far less.

Error Types

Several types of errors may be distinguished. The Navy refers to errors as Class A, B, and C in connection with computers and similar devices. Class B errors arise from mathematical approximations used in design, Class A from constructional and operational imperfections, and Class C errors are the sum of the first two. We may also classify errors in various other ways. For example, on the basis of time of occurence, an error may be:

1 – Constant, when its value does not change with time. A misplaced index mark would cause a constant error;
2 – Transient, when it has momentary effect only. A voltage surge could introduce such an error;
3 – Periodic, when it cyclically repeats. A gear which is eccentric to its bearing might introduce this;
4 – Random, when its occurence follows no consistent pattern. Such errors are often due to small machining discrepancies which affect results haphazardly as to amount and sense.

On a place basis, errors may be classified according to:

1 – Quantity directly affected, such as *x*, *y*, or other problem variable;
2 – Order of entry. An error which enters a computation at an early stage may have much greater effect than one which does so at a later stage. When an error is integrated twice its effect will tend to build up as the square of the argument of integration.

We may also classify errors as to whether they are:

1 – Independent of problem quantities;
2 – Proportional to, or otherwise dependent upon, problem quantities, e.g., percentage errors.

We can also make a breakdown of errors according to:

1 – Machine errors, due to design or functional shortcomings;
2 – Personnel errors, due to mistakes in programming or functional or engineering mistakes in manipulation.

Error Sources

The sources of errors are all too numerous. They arise basically from the impossibility of producing and maintaining a physical device or system which exactly represents its theoretical ideal. In analog use, such dimensions as length and angle can be realized only to tolerances which are often significant fractions of the quantity representation. For example, a machining tolerance of 0.0001 inch is frequently the best that can be done unless extraordinary procedures are adopted. If an inch represents a quantity, the accuracy to be expected is consequently less than one part in 10,000 as more than one tolerance will normally enter the representation. Moreover, there is a possibility that thermal expansion or aging of the parts may aggravate the error. Electrical components such as resistors and capacitors are usually less accurate than machined parts and are even more subject to thermal effects and aging. Vacuum tubes, transistors, crystal diodes, and the like are still more variable. When they are used as other than on-off devices they can really strain the designer's ingenuity to minimize the potentialities for error. Two very prolific sources of error, then, are to be found in *dimensional tolerances* and *material shortcomings*. A third general source of errors exists in a computer's *environment*. This comprises such factors as ambient temperature, humidity, and vibration. An uncontrolled ambient temperature may bring about the thermal effects already mentioned. On top of this, local temperature variations (hot spots) can adversely affect component values and unit performances. Excessive humidity can lower some electrical resistances, cause damage by rust, and impair the performance of many electrical and mechanical units which are not adequately protected. Dust may also contribute to substandard operation. For example, it frequently prevents relay contact closures. Low atmospheric pressure is encountered in airborne environments. Vibration may be present in both mobile and stationary situations. All of these environmental factors, and others as well, are potential sources of errors.

Error Analysis and Reduction

Error analysis may be both theoretical and experimental. Examples will be found in the references and elsewhere in computer literature. Using the theoretical approach, we first make a mathematical analysis of the equations to be used. We compute the maximum (or the probable) effects on the results due to the types of error to be expected in each part of the equations. The errors will generally be regarded as small quantities so that the principle of superposition applies. That is, we first treat each error as though it were the only one present. After all of them have been so treated, we compute the combined effects. To determine the effect of an individual error we take the partial derivative of the affected expression with respect to the erroneous quantity. We evaluate this derivative for the most pessimistic case, and then multiply the value by the expected maximum value of the error. As an example, suppose the problem uses:

$$z = x^3 + y^3$$

We desire to know the effect on z of an error in x. The partial derivative, $\partial z/\partial x$, is $3x^2$ and the error in x is denoted by δx. The effect of δx on z will then be $3x^2 \cdot \delta x$. If the greatest value of x in the problem is 10, $3x^2$ cannot exceed 300. Hence, if the δx is 0.002 or less, the effect of an error in x on z will be 0.6 or less. If our similar analysis for y gives the same result, the effect on z of errors in both x and y will be 1.2 or less. We have used maximum values in our example. If we apply probability theory, we will find that the probable errors are less.

We can make an experimental error analysis by comparing actual computer performance with manually computed or theoretically known results. For example, if the computer can generate an ellipse, it can be judged on how well it returns to its starting point. We can also compare successive computer performances. We will then vary the program between runs so as to develop the same results while using alternate units, channels, or sequences of operations. We can also compare one computer with another. Another technique is to introduce parameter variations tantamount to errors and study their effects. In our experimental procedures we will try to vary the ranges of values used, the operational setups, and so forth. This will enable us to determine the domains in which the computer can be depended upon to achieve the results required and those in which its performance is marginal.

The first point of attack in error reduction is, of course, in the design of the computer. Many ingenious schemes are used to prevent the occurence of as many foreseen sources of error as possible, or at least to reduce their effects to manageable proportions. Means may be provided for compensating for errors which cannot be designed out. For example, a precision integrator lead screw may be equipped with a cam mechanism to correct the residual errors determined on calibration. Another widely used method of error reduction is error cancellation. In this method, two units each of which develops an error are so arranged that the errors will offset each other, either completely or in major part.

III:9 SYSTEM AND SUPPLY CONSIDERATIONS

In general, a computer will be a part of a larger system (using "system" in a broad sense). The system into which the computer is to be incorporated may be one for process control, for test data reduction, for mathematical research, for educational instruction, or for other purposes. The character of this system will tend to determine the objectives which the computer must meet, and in fitting the computer to the system there are many questions to be considered. Some of these questions will relate to the computer itself, but many others will not. These questions cannot be fully defined, of course, until the system requirements are known. However, there are some general considerations which may well apply to a particular case. In the following paragraphs will be listed a number of such considerations as a help towards the compiling of a more specific list as needs become known. Experience has shown that newcomers to the field of mechanized computing tend to overlook some of these collateral matters.

In most cases auxiliaries will be required. These may include such items as input and output devices, spare parts, supplies, calibration and test equipment, and the like. Those needed should be studied as to suitability, availability, and so forth.

Size and weight of the computer and collateral equipment may have a direct bearing on their acceptability, especially for mobile applications. The building in which the computer facility is to be housed may require modifications. It may be inadequate to accommodate a large installation, or ducting and air conditioning may be required.

Cost is usually an important consideration. Both first cost and the costs of maintenance and operation should be considered, including those for special personnel. Some computers are available on rental as well as by purchase. If a computer installation is to be acquired by contract, such details as time of transfer of title, shipping method, installation and removal costs, performance penalties, etc., must be taken into account.

Personnel of adequate skills in sufficient numbers for the operation and maintenance of the system may require special provisions. Appropriate training of an existing staff may be required, or contract arrangements may be made with a supplier to provide operating and maintenance services.

Power requirements, including those for any supplementary services such as ventillation, air conditioning, and lighting, should be determined as to character, quantity and tolerances. The effects of power outages and possible preventive measures may need to be considered, particularly if a critical process is involved.

The environment which the installation will be expected to meet and that which it requires may need consideration, especially for airborne applications. Temperature, humidity, dust, vibration, and other factors may be involved.

Reliability may be an important or even vital consideration. One useful measure of reliability is called *operating ratio*. It may be expressed in percentage and be defined as the time the computer operates correctly (disregarding operator errors) as a portion of the time it is required to operate, excluding a reasonable allowance for maintenance time (as agreed in advance). Another measure is known as *mean free time* between computer errors. Some reliability will be built in and some will depend upon operating and maintenance procedures. It will be promoted by conservative design, derating of components, specially produced components or special selection of run-of-production components, and the like. There should be adequate means to monitor possible trouble spots and to give early warning of incipient failures, perhaps with appropriate automatic action. Marginal checking (to reveal components which are near failure) and diagnostic routines (to locate trouble spots) may form a part of preventive maintenance. For example, electronic components may be checked by using test voltages, currents, or frequencies which will indicate marginal performance, and computing routines can often be devised to pinpoint the diagnosis of unsatisfactory performances. Standardization of components, especially electronic chasis, will tend to facilitate maintenance and to increase reliability, besides reducing the sparing problems.

The question of whether or not to build into a computer additional hardware to check mathematical and other operations has given rise to two schools of thought. This is especially so in the digital computer field. One school favors providing means for checking nearly every function. The other argues that doing so often reduces speed and increases size, cost, and the number of sources of malfunctioning; and contends that careful design and operation, including suitable programmed checks, are adequate. This question has not been so prominent in the analog computer field, but it deserves consideration and perhaps some compromise solutions.

Specifications, inspections, and tests may require formulation, especially acceptance tests. A history of prior tests and performances may also be helpful.

Operating speed may require detailed study, especially as some commercial claims tend to be misleading. Excessive speed may militate against accuracy and complicate maintenance. On the other hand, insufficient speed may make it difficult or impossible to fulfill system objectives.

III:10 FUTURE PROSPECTS

There is certainly a bright future ahead for analog computers of many sorts. While digital computers have recently tended to steal the show by their very impressive complexity and performance, their analog cousins have by no means been superceded. There are far more analog computers of all sizes than there are digital ones and this ratio is sure to continue into the foreseeable future. It is true that the medium and large capacity digital computers are becoming more numerous by leaps and bounds, and may have already overtaken the number of comparable analog installations. But on the lower level of small devices, the analog device can offer advantages that its digital counterpart will be hard pressed to meet. These small analog computers will, of course, be special purpose devices with very limited flexibility of program.

The two paramount advantages of the digital devices are precision and flexibility. But where high precision and wide versatility are not required, the analog device often can offer simplicity, low cost, small size, light weight, simple maintenance, and exceptional reliability. In other words, the digital device buys precision and flexibility at a cost of complexity and multiplied sources of trouble. As for speed, either method may have a large margin on the other depending upon the specific application. While a digital computer may be able to perform some operations at a rate of 10,000 per second, it may require several hundreds of operations to produce a result. An analog computer may make the same result available from very few parts in a matter of microseconds. Again, the high speed of the digital computer may, in another case, far outstrip the lumbering action of its analog competitor. If speed is a primary concern, either type will turn to electronic rather than to mechanical or even electromechanical methods.

One technique which will tend to justify more elaborate computer installations is that of time sharing. That is to say, a more elaborate but adequately flexible computer may furnish services which would otherwise require a number of smaller devices. The master computer would be made available to the individual services on a rotational basis. Each would thus utilize a more powerful device. This sharing could effect an overall economy of cost, space, etc. In this plan, the implicit need for flexibility will tend to throw the procedure into the digital field, but not invariably.

The increasing demand for computers of all varieties springs from the ever widening mechanization of our economy. There is a growing realization that devices can relieve human beings of much labor, not only physical, but also mental. Computational labor may be not merely numerical but also logical. The machine usually outperforms the human in such matters as cost, endurance, imperturbability, and so forth. This realization of the potential superiority of the machine over the man has become commonplace in military engineering. In part, this is so because the speeds of vehicles and missiles and the conditions under which they are utilized have imposed requirements as to performance and environment beyond human capability, or rapidly approaching its limits. However, the realization of the possibilities of control mechanization has heretofore not been so widespread in industry as in the military field. Now it is rapidly catching up. It is true that many processes have been mechanized up to a certain level, but the level can be raised and the number of processes can be greatly increased. We can, therefore, expect a rapid growth of mechanization requiring computing functions. The smaller examples will become much more common. The great cost of the more elaborate installations, however, will tend to confine them to the larger industrial, educational, and governmental organizations.

Very few present-day computers are strictly all analog or all digital. It can be expected that future computers will take considerable advantage of the possibilities of combined analog and digital methods. There are fashions in computers. For example, a few years ago there was a sharp swing to binary arithmetic. This arithmetic is adaptable to a flip-flop but quite unnatural for a decimal-trained human. The fashion has now considerably yielded to binary coded decimal and other systems more acceptable to an operator or technician. Similarly, we may soon expect that digital representation will be less fashionable in those cases where analog procedures can be more effective. The near future may also see less insistence on the use of electronics when mechanical or other devices can be more advantageously employed.

There are new developments which portend impressive changes in the computer fields, both digital and analog. Among these are transistors and magnetic devices for amplifying and switching. Transistors offer drastic reductions in size, weight, and power, with virtual elimination of the heat-dissipation problem. Tiny ceramic magnetic cores are being applied to memory and switching functions. They permit large capacity units of small size with rapid random access. Many other new developments are in the laboratory today; some of them are likely to be found in tomorrow's computers.

SECTION IV

OTHER TYPES OF AUTOMATIC COMPUTING MACHINES

IV:1 TYPES OF AUTOMATIC COMPUTING MACHINES THAT ARE NOT DIGITAL OR ANALOG COMPUTERS

The term "automatic computing machinery" is often used with a broad meaning: "automatic machinery for processing information reasonably." In fact, some people prefer the term "automatic data processing machinery" since "data" is a short word meaning "information."

We have said a good deal about automatic analog computers and automatic digital computers. These are the two main divisions of automatic computing machinery. But by no means do they constitute all the types of machines which handle information reasonably and automatically. We shall now look at machines which are not computers in the ordinary sense, or which include other functions besides computing proper.

By "reasonable operations" on information, it may be worth repeating, we mean operations with information that in the last analysis can be defined by tables of all the combinations and cases of expressions, each made up of a series of ones and zeros or else correlations of measurements. Thus "reasonable operations" express first logic, then arithmetic, and finally all of mathematics and reasoning.

The question of what is sufficiently reasonable behavior to call a piece of equipment "computing equipment" will trouble us slightly. A machine that only copies (such as a camera), or a machine that only translates one form of character (such as a pattern of punched holes in paper tape) into another form (such as a character printed or typed on a piece of paper) – are these examples of automatic computing machinery? Actually, some of the people in the field are interested in certain of these machines also, and so it is convenient to treat them as additional examples of automatic computing machinery. There is not much consistency about it. A television receiver is not often considered to be computing machinery, but a similar machine that just copies, the facsimile machine, is classified as such by some computer people.

The question of what is automatic and what is not will also trouble us to some extent. For example, a Friden desk calculating machine will accept and store two ten decimal digit numbers; then when a button is pressed, it will automatically multiply them together, by an automatic process of repeated addition and shifting depending on the digits in the multiplier. Is this automatic? In one sense it is, and yet from the point of view of a machine which can carry out a flexible program of instructions, the desk calculator had better be called semiautomatic.

Types of Machines

What, then, are the types of existing machines that may well be considered automatic machinery for handling information reasonably, and yet are not automatic digital or analog computers? Such machines include those in the following list, which for want of a better order, has been made alphabetical. The word "automatic" should be understood in nearly all cases.

—Accounting-bookkeeping machines, which take in numbers through a keyboard and print them on a ledger sheet, but are controlled by "program bars." These program bars, according to the column in which the number belongs, cause the number to enter positively or negatively in any one of several totaling counters, which can be optionally printed and cleared.

—Astronomical telescope aiming equipment, which adjusts the direction of a telescope in an observatory so that it remains pointed at the small section of the heavens that an astronomer intends to study.

—Automobile traffic light controllers, which take in indications of the presence of motor cars usually from the operation of treadles in the pavement, and give out signals, according to a program of response to the volume and density of traffic.

—Control systems for handling connected or flowing materials, which will take in indications of flow, temperature, pressure, volume, liquid level, etc., and give out the settings of valves, rollers, tension arms, etc., depending on the program of control.

—Control systems for handling separate materials, which will move heavy blocks, long rods, or other pieces of material to or from stations and in or out of machines, while taking in indications furnished by the locations of previous pieces of material, the availability of the machines, etc., all depending on the program of control.

–Data sampling systems, which will take in a continuous voltage or other physical variable and give out samples, perhaps once a second or perhaps a thousand times a second; this machine may be combined with an analog-to-digital converter, so that the report of the sample is digital, not analog.

–Digital-to-analog converters, which will take in digital numbers and give out analog measurements.

–Facsimile copying equipment, which scans a document or picture with a phototube line by line and reproduces it by making little dots with a moving stylus or with an electric current through electrosensitive paper.

–Fire control equipment, that takes in indications of targets from optical or radar perception and using extensive calculating equipment puts out directions of bearing and elevation for aiming and time of firing for guns, according to a program that calculates motion of target, motion of the firing vehicle, properties of the air, etc.

–File-searching machines, which will take in an abstract in code and find the reference alluded to.

–Flight simulators, which will take in simulated conditions of flight in airplanes, and the actions of airplane crew members, and show the results, for training purposes.

–Game-playing machines, in which the machine will play a game with a human being, either a simple game such as tit-tat-toe or nim (which have been built into special machines) or a more complicated game such as checkers, chess, or billiards (which have been programmed on large automatic digital computers).

–Inventory machines, which will store as many as ten thousand totals in an equal number of registers, and will add into, subtract from, clear, and report the contents of any called-for register (these machines apply to stock control, to railroad and airline reservations, etc.).

–Machine tool control equipment, which takes in a program of instructions equivalent to a blueprint, a small size model, or the pattern of operations of an expert machinist, and controls a machine tool so that a piece of material is shaped exactly in accordance with the program.

–Navigation and piloting systems, which will take in star positions, time, radio beam signals, motion of the craft, etc., and deliver steering directions.

–Printing devices of high speed, which will take in punched cards or magnetic tape and put out printed information at rates from 600 to 2000 characters per second.

–Punch card machines, which will sort, classify, list, total, copy, print, and do many other kinds of office work.

–Railway signaling equipment, which, for example, enables a large railroad terminal to schedule trains in and out every 20 seconds during rush hours with no accidents and almost no delays.

–Reading and recognizing machines, which scan a printed figure or letter, observe a pattern of spots, route the pattern through classifying circuits, recognize the figure or letter, and activate output devices accordingly.

–Spectroscopic analyzers, which will vaporize a small sample of material, analyze its spectrum, and report the presence and the relative quantities of the chemical elements in it.

–Strategy machines, which enable military officers in training to play war games and test strategies, in which electronic devices automatically apply attrition rates to the fighting forces being used in the game, growth rates to the industrial potential of the two sides, etc.

–Telemetering, transmitting, and receiving devices, which enable a weather balloon or a guided missile to transmit information detected by instruments within it as it moves; the information is recorded usually on magnetic tape in such fashion that it can later be used for computing purposes.

–Telephone equipment including switching, which enables a subscriber to dial another subscriber and get connected automatically.

–Telephone message accounting systems, which record local and long distance telephone calls, assign them to the proper subscriber's account, and compute and print the telephone bills.

–Test-scoring machines, which will take in a test paper completed with a pencil that makes electrically conductive marks, and give out the score.

- –Toll recording equipment, which will record, check, and summarize tolls for bridges, highways, and turnpikes.
- –Typing machines of high speed, which will store paragraphs and combine them according to instructions into correspondence or form letters, stopping and waiting for manual "fill-ins" if so instructed.
- –Vending machines, which will accept different coins, make change, give out coffee, soft drinks, sandwiches, candy, stockings, and a host of other articles, or else allow somebody to play a game for a certain number of plays, etc.

The foregoing list of twenty-eight kinds of automatic computing machinery is of course not complete. New types of such machinery are coming into existence from week to week and from month to month. New applications of such machinery are constantly being made. Not even all the existing types are in this list, for some of them are highly secret.

But enough has been mentioned here, without drawing on human imagination or human anticipations of the next hundred years, to show conclusively the importance and the far-reachingness of automatic machinery for handling information, and to raise an important question, which we shall discuss in the next chapter: What are the components of automatic computing machinery?

IV:2 THE COMPONENTS OF AUTOMATIC COMPUTING MACHINERY

The fact that there are at least two dozen types of automatic computing machinery now existing suggests that it would require an encyclopedia to tell the whole story about all of them. Furthermore, information about some of the types, such as automobile traffic light controllers, is said to be closely guarded by the makers as their trade secrets. Nevertheless, it is quite possible to make some generally true statements about all types of automatic computing machinery since each contains basically a selection from the same class of components. Why is this so? And what are these components?

For machines to handle information automatically, special types of hardware had to be developed. These are the customary components of automatic computing machinery. They are inventoried and partly described in the outline which follows. Of course, much of the description given in foregoing parts of this book about digital and analog computers applies with little change to the components of all kinds of automatic computing machinery.

This outline shows rather clearly the difference between automatic computing machinery as such, and automation, which is a broader and more inclusive idea. The man interested in automatic computing machinery centers his attention on the receipt, manipulation, and delivery of information. The man interested in automation, however, is concerned with sensing devices, acting devices, and rendering them automatic; he draws on the automatic computer man's knowledge to cause the sensing and acting devices to act reasonably together.

Perhaps this discussion would hardly be complete without pointing out that there is a whole great class of efficient and compact data-processing devices which we know exist, and yet none of them has currently been adapted for use in automatic computing machinery or installations of automation. These are the chemical or biochemical devices used in animals and man for storing and utilizing information and experience. Some experimentation in electrochemical devices for storing and computing has in fact taken place at the Mellon Institute, Pittsburgh, and doubtless in some other places. Certainly, it is evident that great possibilities exist for future design and development of chemical and electrochemical components of automatic computing machinery.

COMPONENTS OF AUTOMATIC COMPUTING MACHINERY – OUTLINE

1. Storage mediums, for both internal and external storage:
    - Punch cards
    - Punched paper tape
    - Magnetic tape
    - Magnetic wire
    - Metal plates

5. Output devices:
    - Visual displays: oscilloscope screen
    - Electric typewriter, or other electrically operated office machine
    - Automatic plotter, which will trace or plot a curve according to information delivered by the machine
    - Line-at-a-time printer
    - Facsimile printer
    - Photographic recording
    - Matrix printer, that forms each character by a pattern of dots
    - Positioning devices, that may operate a valve, roller, tension arm, etc., resulting in control of a manufacturing operation or process

Plugboards, i.e., panels of patch cords

—All these physical forms express machine language; when inserted into a machine, they give the machine information and instruction; when left in a filing cabinet, they hold information and instructions in reserve for later use. Sometimes it is the whole area or volume of the storage medium which is used, as in the ordinary punched card. Sometimes it is only the edge which is used, as in edge-punched cards or edge-slotted metal plates.

2. Storage mediums, internal only:
    - Magnetic drums
    - Magnetic tape units
    - Magnetic cores, arranged either one-dimensionally as in a magnetic shift register, or in two or three dimensions as a magnetic core matrix memory; they are made of special iron alloys or of iron oxide ceramics called ferrites.
    - Electrostatic storage tubes, in particular cathode ray storage tubes
    - Delay lines, of mercury, quartz, or nickel
    - Relays, in relay registers, and stepping switches
    - Electronic tubes, in registers of flip-flops, counting rings, etc.
    - Switches: toggle switches and dial switches
    - Buttons and keyboards
    - Rotating shafts
    - Voltages
3. Calculating and controlling devices:
    - Relay and stepping switch circuits
    - Electronic tube circuits
    - Rectifier circuits, using diodes: electronic tube, germanium, selenium, silicon
    - Transistor circuits.
    - —Also the circuit elements auxiliary to each of these four kinds of circuits: amplifiers, pulse transformers, voltage regulators, etc.
    - Analog computing elements: resolvers, synchros, integrators, adders, etc.
    - Automatic process controllers as such, pneumatic, electronic, hydraulic, etc.
4. Input devices:
    - Buttons
    - Switches
    - Paper tape readers: mechanical, electrical, photoelectric
    - Punch card readers: mechanical, electrical, photoelectric
    - Magnetic tape readers
    - Automatic curve followers: photoelectric
    - Scanners: electric, photoelectric
    - Sensing instruments of all kinds
    - —The category "sensing instruments" verges into the science of instrumentation, where humidity, temperature, pressure, volume, flow, liquid level, and many other physical variables can be measured and reported to a machine in machine language.

SECTION V

MINIATURE COMPUTERS AND THEIR USE IN TRAINING

V:1 TRAINING FOR AUTOMATIC COMPUTERS

The field of automatic computing machinery has greatly expanded in recent years, and is clearly headed for greater expansion still. There are over 100 types of automatic computers, and more than a 1000 instances of such machines. In a few more years there will be over 10,000.

Contrary to first impressions, the users of these machines have to hire more and not fewer people to operate and maintain them, although there may be compensating reductions of personnel in other categories. The reason is that very much more information than before can be handled profitably with these machines. A guess may be replaced by a calculation, and ignorance by a known probability or certainty. This is valuable. Therefore, a much larger volume of work (information, answers to questions) is produced than before automatic computers were applied.

We can estimate roughly that each large automatic computer requires a staff of from four to forty persons to keep it running successfully: engineers, mathematicians, programmers, technicians, maintenance men, etc., all especially trained in regard to computers. This number of people is required to staff a computer after it has been delivered to the user; it does not include the engineers and other skilled persons employed by the manufacturer to construct the computer in the first place.

Producing trained people for operating and maintaining computers is no easy task. A useful automatic digital computer is a giant. It contains hundreds of electronic tubes; thousands of resistors, capacitors, diodes, etc.; miles of wire; and great quantities of other hardware. Such a machine is difficult to understand in its entirety.

But trainees must understand computers: how to construct them, how to program them, how to maintain them, how to apply them. How shall we train these people? What methods are open to us?

Sources of Training

There are four main kinds of training currently given. First of all, there are the short courses taught by the manufacturer of the computer to employees of the user. These are certainly useful and essential; but there is pressure to keep paid employees on useful work, and such courses tend to be less complete than might be desirable in many cases.

The second kind of training currently available is carried out by the organization using the computer, and consists mainly of training on the job. This too may be successful, provided the employees have at least some basic knowledge, and that adequate opportunity to learn can be allowed by the user, considering his requirements. Here again, the high cost of an automatic computer produces a pressure which limits the thoroughness of such a program.

A third kind of training has also begun to appear. This consists of short courses of study, generally summer courses, offered by technical schools and universities. Generally, they are schools which have large-scale automatic computing equipment, and the course includes access to it.

A fourth kind of training consists of regular full-semester courses, given by schools and universities, as a part of programs of study including mathematics, electrical engineering, etc. Such schools should produce a quantity of mathematicians, computer engineers, accountants, methods engineers, and other men, all trained in some of the aspects of automatic computing machinery. Many university departments need to modify their curriculum to include such courses.

Access to a Computer

One main requirement in every undertaking to teach persons about automatic computers is access to one. Obviously, those schools that have automatic computers are the ones that offer courses in their operation. Ideally, every school that teaches mathematics should possess an example of an automatic computer, so that students might be trained not only in the process of doing arithmetic by hand, but also in the process of doing arithmetic by automatic computer. However, most automatic computers are monopolized by "VIP's" – very important problems. Since they are expensive and valuable machines, they have an affinity for important work to do, important problems to solve. An automatic computer may rent for $300 an hour, and it is hardly possible to allow an individual student a couple of hours of actual instruction and experiment on such a machine, as if it were a desk calculator. A second factor is that many schools can afford to spend not more than a few hundred dollars towards an automatic computing machine, while the current lowest cost of a digital computer is about $40,000. Besides, a useful machine is so complex that most students would have to use more time than they could spare in order to find their way through the complexities.

How shall we get around these obstacles?

Special Training Devices

Similar to this problem is the problem of how to train a new crew to fly an airplane. The U. S. Navy has given particular attention to airplane crew training, and during World War II set up a division called the Special Devices Division, whose first mission was to develop special training devices for flying planes. Later their mission was extended to special training devices for operating other kinds of complex equipment, and for grasping complex ideas such as the movement and relation of air masses to produce the weather. Other branches of the Armed Services have adopted this method; and now more than two hundred realistic "flight simulators" are in use for the training of crews of various types of planes.

But this too is an expensive solution. Is there any inexpensive solution?

It is now possible to obtain a small "electric brain construction kit" which is an introduction to the design of arithmetical, logical, reasoning, computing, puzzle-solving, and game-playing circuits. After studying the manual, the student can make for himself over thirty small machines that will reason and compute automatically although they will not carry out an automatic sequence of instructions. By experimenting with these machines, he can obtain first-hand experience in how an automatic computer works. The materials in the kit however are not necessary; some persons will prefer to construct their own small machines using other materials. Many amateurs and scientists using home workshops have constructed similar small machines with switches and relays.

A more complicated, yet still simple, digital computer which is really automatic and which displays almost all the properties and principles of a giant automatic digital computer, can also be constructed by using ordinary hardware. Such a computer is within the time and expense budget of many schools and some individuals, and can never be monopolized by "very important problems." The first of these rudimentary automatic computers designed and constructed for the purposes of training, education, lecturing, and teaching, is the miniature automatic digital computer called "Simon", which we shall now describe at length.

V:2 SIMON: ITS HISTORY AND MAIN FEATURES

Simon is a miniature automatic digital computer, which like its namesake Simple Simon of Mother Goose fame is not a "giant brain" but a simple-minded one. It is not able to do any useful calculating, but it is helpful in training, instructing, and lecturing. Simon exhibits in small dimensions the properties of automatic computers, particularly automatic digital computers.

Simon when first constructed in 1950 knew only the numbers 0, 1, 2, and 3, and could perform only four simple logical and mathematical operations: "addition, negation, greater than, selection." But the machine possessed the two unique properties that define any true mechanical brain: it could transfer information automatically from any one of his registers to any other, and it could perform endlessly long sequences of reasoning operations.

In contrast to a modern automatic computer which performs 10,000 arithmetical operations a second, Simon performs one operation in about two thirds of a second. In contrast to Univac, which can refer to over 10 million numbers, Simon can refer to only 16 numbers at one time. In contrast to the two Model V Bell Telephone Laboratories calculators, which can conceive of 351,000,002 numbers, Simon when first built could conceive of only four numbers. But the machine was designed and built to exhibit in simple understandable form the essential principles of any mechanical brain, with a minimum of complexity, and this it does well.

Physical Construction

Prior to November, 1950, Simon was only a hypothetical machine. It was then redesigned and built as a real machine, handling numbers 0, 1, 2, and 3. During the summer of 1950 circuits were installed in Simon for arithmetical carrying, and five additional logical and arithmetical operations. As a result; Simon could take in numbers as high as 255 and put out numbers as high as 510. Since then, over 400 sets of plans for Simon have been distributed and at least two more Simons have been built, one in California, one in Kansas. The final actual cost of Simon was about $270 for the materials and about $300 for some of the labor of wiring. The total figure of $570 does not include the cost of the designing of a good half of the labor which was contributed.

Even in the first hypothetical designs for Simon it was decided that the principal elements should be relays rather than electronic tubes. Circuits involving relays are considerably easier to understand than those involving tubes. In fact, they can be understood in terms of yes and no, that is, of current flowing and current not flowing. A survey of war-surplus stores in November 1949 indicated that we* could reasonably use certain relays with two double-throw contacts and an additional single-throw contact. These operated at 24 volts, and had a 3000-ohm resistance. We also acquired a second-hand stepping switch, and modified it with a coil that would energize at 24 volts. For giving Simon instructions, we selected a five-hole paper-tape feed and a second-hand telegraph tape transmitter. A frame for mounting the hardware, a front panel of black plastic, switches, lights, rectifiers, condensers — these constituted nearly all the rest of Simon.

The original Simon was planned on two tape feeds, one for two-hole paper tape to receive numbers, and one for four-hole paper tape to receive instructions. Simon as actually constructed contained only a single tape feed using five-hole paper tape, on which both numbers and instructions were entered in a systematic sharing of space and time.

Simon (see Figures 40 and 41) is about 24 inches long, 15 inches wide, and 6 inches high, and occupies about 1¼ cubic feet of space. It weighs (not counting power supply) about 39 pounds. It draws at most about 5 amperes d.c. at 24 volts.

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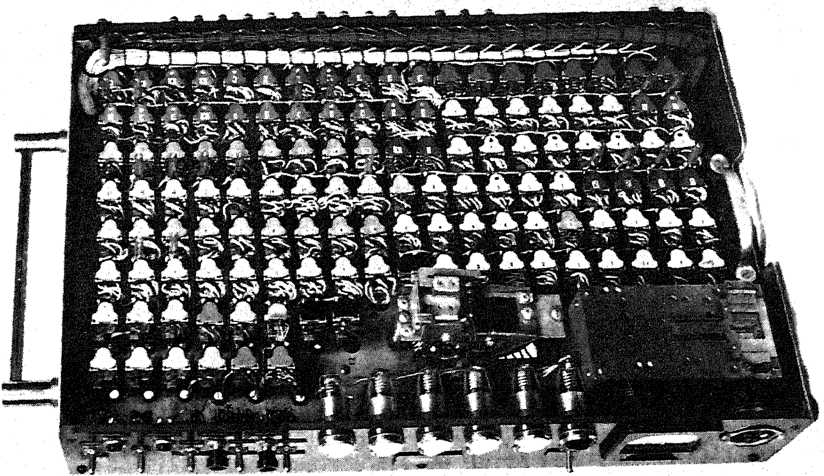
* The pronoun refers to E. C. Berkeley and Associates who originally planned and built this equipment.



Courtesy "Radio Electronics"; Copyright 1950-51 by Gernsback Publications, Inc.

Figure 40.

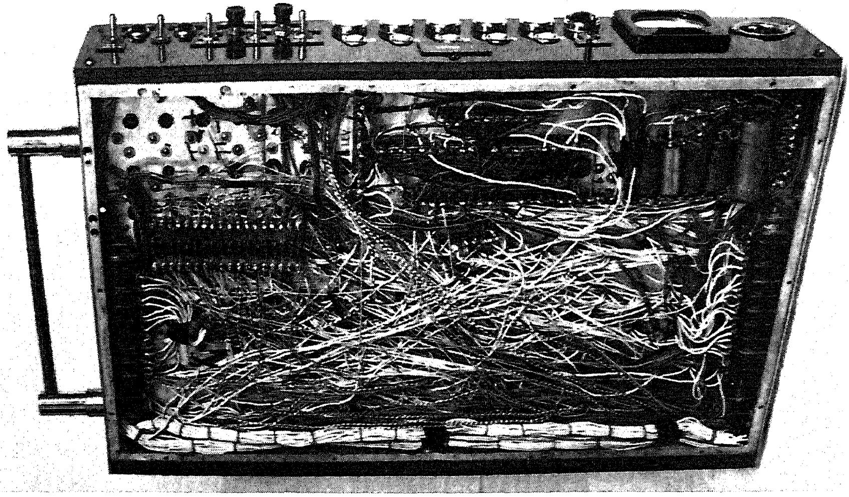


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Figure 41.

The front panel of Simon (see Figure 42) is 24 inches wide and 6 inches high, and has the following hardware mounted on it:

- six lights, five for output information where Simon shines answers, and one that shows whether power is on or off;
- nine buttons, four of them at the left for operating the machine, and five at the right for putting information into the machine (either numbers or instructions in the form of five binary digits of information);
- six buttons, one for turning the power on, which starts the machine, and five other buttons, mainly in order to provide either automatic operation (using the punched paper tape passing through the tape feed) or manual operation (using one's fingers on the buttons of the machine); and
- a meter, which shows the voltage at which the machine is operating, ordinarily with Simon around 30 volts.

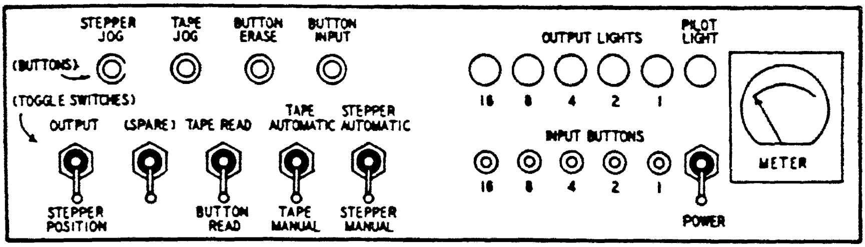

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Figure 42.

Just behind the front panel, and open from the top, appear all the essentials of Simon: the tape feed at the right front; the stepper very close to it; and some 129 relays (of which about 8 are spares, available for increasing Simon's capacity). More explanation of the hardware of the machine is given in the next two sections.

The Future of Simon

Although Simon is at present a machine capable of dealing with numbers up to 255 and performing some nine reasonable operations, this is not the end of the story.

First of all, Simon itself can grow. It possesses all the essentials of a mechanical brain, and other circuits increasing its capacity can be added to it. In Stage 1 it handled numbers 0, 1, 2, 3; by the inclusion of arithmetical carry circuits, it became able to handle numbers up to 255. The present limitation on the size of numbers which it can now handle is a limitation of memory: so long as Simon has only 16 registers, each of which can store only two binary digits, it will be severely limited. The obvious thing to do is to add a good deal more memory; this could be done by connecting a magnetic drum, and providing for translation from magnetized spots on the drum to information stored in relays, and vice versa.

Besides its own future development, Simon may lead to the building of other complete small mechanical brains. The simplicity and low cost of such small machines may make them eventually as attractive to scientific amateurs and serious students as radio transmitters and small telescopes.

V:3 SIMON: NUMBERS, OPERATIONS, AND PROGRAMMING

In setting out to design any automatic computer, small or large, two questions that need to be decided at an early stage are the following: What sorts of concepts should the automatic computer handle? What sorts of reasonable operations with these concepts should the automatic computer perform?

Sets of Concepts and Operations

For an automatic computer as well as for mathematics, a set of concepts and operations with those concepts constitutes a *mathematical system.* The mathematical system which people most commonly deal with is the set of ordinary numbers and fractions with the operations addition, subtraction, multiplication, and division, which make up ordinary arithmetic.

Now there exist in mathematics not only mathematical systems that are very large, containing millions of numbers or elements, such as the example just mentioned, but also some systems that are very small, containing only a few numbers or elements. Some of these small systems are in common use in daily life as well as recognized in mathematics.

For example, there is the mathematical system of the days of the week—Sunday, Monday, Tuesday, Wednesday, Thursday, Friday, and Saturday – together with the mathematical operations "so many days later," "so many days earlier." This system has an addition table but no multiplication table. One of its rules is that: "The day six days later is the same as the day one day earlier." (For example, the day six days after Sunday is Saturday, and the day before Sunday is Saturday.) It would be quite possible to build a miniature computer which would take in any year, month, and day and give out the day of the week.

Another mathematical system in common use consists of six elements: right, left, up, down, back, front. A smaller one contains North, East, South, West. Perhaps the commonest and most useful of all mathematical systems has just two elements: "yes" and "no"; or under other names, "on" and "off," "true" and "false," etc. Mathematically we can use the binary digits 1 and 0.

Simon's Concepts

When constructing Simon, we chose out of these small mathematical systems, one containing four elements, which may be called 0, 1, 2, and 3. With this system we could portray at least some of the numerical side of mathematics, and still handle the logical side of "yes" and "no." We named these four elements, 0, 1, 2, and 3, but in order to represent these numbers in the machine, we used interchangeably with these names their binary representation 00, 01, 10, and 11.

There were a total of sixteen registers in Simon where any one of these four numbers could be stored. Each register consisted of a pair of relays; if 1 designates the state "relay energized," and 0 designates the state "relay not energized," then the pair of relays could represent 00, 01, 10, and 11 by the possible arrangements of their states.

After the first stage of Simon had been finished, we considered how to make the machine more versatile and soon came to the conclusion that by use of pairs of registers together, it was possible to represent all the numbers from 0 to 15, in the form 00 00, 00 01, 00 10, 00 11, 01 00, . . . , 11 10, 11 11. Here the first pair of binary digits represents the state of the two relays in one register used to store the left-hand half of the number, and the second pair of binary digits represents the state of the two relays in the other register used to store the right-half of the number. In order to give full significance to these numbers of "double precision," however, we had to be able to determine the carry from adding the right-hand halves of two numbers to be added, and use this carry if any to modify the sum of the left-hand half of the two numbers being added. This is reflected in the operations described below.

In this way the sixteen registers of Simon could be used to store eight numbers ranging from 0 to 15. Then if we associated registers into sets of four we could store four numbers from 0 to 255, ranging from 0000 0000 to 1111 1111.

So much for the numbers which Simon could store. What about the instructions? Currently, all the instructions for Simon are stored as words composed of five binary digits expressed as punched holes in the five-hole punched paper tape fed through the tape feed. Even a small program requires quite a large number of instructions. With the limited storage capacity of Simon, it would be possible to store at most about four instructions. These would require ten of the registers, leaving only six registers of two binary digits for calculations. Not until Simon becomes a magnetic drum computer will it be a stored program calculator.

Simon's First Four Operations

The first four operations which Simon was designed to perform were addition, negation, greater than, selection. Because the whole system of elements contains only four numbers 0, 1, 2, 3, it is small enough so that we can define the operations by listing all the cases.

The definition for addition is shown in Table 2.

TABLE 2
OPERATION 1: ADDITION, WITHOUT CARRY

$c = a + b$

a \ *b*:	0	1	2	3
0	0	1	2	3
1	1	2	3	0
2	2	3	0	1
3	3	0	1	2

Addition, as appears from the Table, is regular addition, except that the largest multiple of 4 is subtracted from any number 4 or greater; it is addition modulo 4; thus, 1 plus 2 is 3, but 3 plus 3, which is 6, becomes 2 by subtracting the 4.

The definition for negation, "finding the negative of," is shown in Table 3.

TABLE 3

OPERATION 2: NEGATION, WITHOUT CARRY, EQUAL TO FOURS COMPLEMENT

$$c = 4p - a$$

$$p = T(a \text{ is } 1, 2, 3)$$

a	p	c
0	0	0
1	1	3
2	1	2
3	1	1

Negation is the operation of subtracting 0 from 0, or 1, 2, or 3 from 4. It is the same as finding the negative of 0, 1, 2, 3 (resulting in 0, –1, –2, –3, respectively) except that a multiple of 4 may then be added so as to make the result positive, 0, 3, 2, 1, respectively. The operation is also the same as finding the complement with respect to 4.

In order to define negation and other operations in automatic computers, we can use a very convenient notation from symbolic logic. Let $T(\ldots)$ stand for the truth value p of ... where ... is a statement, and let p equal 1 if the statement is true and 0 if the statement is false. Then, if p is the truth value of the statement "a is 1 or 2 or 3," the negative of a according to the kind of negation in Simon equals "$4p - a$." Other common names for a truth value are *report, indication.* Every schoolboy is familiar with truth values in the form of check marks and crosses on the answers to his problems. Regular capital letters P, Q, R are used for statements, and their truth values are the corresponding small letters, $p = T(P)$, $q = T(Q)$, $r = T(R)$.

The definition of the third operation "greater than" is shown in Table 4.

TABLE 4
OPERATION 3: GREATER THAN

$$p = T(a \text{ is greater than } b)$$

b:	0	1	2	3
a				
0	0	0	0	0
1	1	0	0	0
2	1	1	0	0
3	1	1	1	0

Here the successful definition of the operation "greater than" to yield a number 1 or 0 that can be stored in a register again depends on making use of the idea of a truth value, in this case, the truth value of the statement "a is greater than b."

The definition of selection is shown in Table 5.

TABLE 5
OPERATION 4: SELECTION

$$c = ap + b(1 - p)$$

p:	0	0	0	0	1	1	1	1
b:	0	1	2	3	0	1	2	3
a								
0	0	1	2	3	0	0	0	0
1	0	1	2	3	1	1	1	1
2	0	1	2	3	2	2	2	2
3	0	1	2	3	3	3	3	3

Here a is a number, b is a number and p is the truth value of some statement P which is the criterion for making the selection. In words, the operation is "Select a if statement P is true, and select b if statement P is false." Clearly if $p = 1$, $c = a \cdot 1 + b \cdot 0 = a$; if $p = 0$, $c = a \cdot 0 + b \cdot 1 = b$. The success of the definition $c = ap + b(1 - p)$ for the purposes of an automatic computer depends on referring to the numbers a and b, and the indication p stored in three registers of the machine. The definition of selection is a noteworthy blend of mathematics and logic.

Simon's Next Five Operations

These were the four operations built into Simon in the first stage, up to May 1950. The next five operations, built into Simon June to September 1950 were the following:

> logical AND; logical NOT (also threes complement); logical OR; addition subject to carry; negation subject to carry.

If *P* and *Q* are two statements, then the statement "*P* AND *Q*" is true if and only if *P* is true and *Q* is true. We can sum up the situation in Table 6:

TABLE 6
LOGICAL "AND"

P	*Q*	*P* AND *Q* = *R*
F	*F*	*F*
F	*T*	*F*
T	*F*	*F*
T	*T*	*T*

Replacing the indications *T* and *F* by 1 and 0, and rearranging the table, we have Table 7.

TABLE 7
OPERATION 5: LOGICAL "AND"

$$r = T(P \text{ AND } Q)$$

p	*q*: 0	1
0	0	0
1	0	1

An operation of elementary algebra which will give r equal to 1 if p is 1 and q is 1, and will give r equal to 0 in the other three cases, is multiplication; so we can write

$$r = p \cdot q \quad \text{or} \quad r = pq$$

If *P* is a statement, then the statement "NOT-*P*," the denial of *P*, is true if and only if the statement *P* is false. In terms of truth values, we have Table 8.

TABLE 8
DENIAL

P	NOT-P = R
F	T
T	F

This may be translated into Table 9.

TABLE 9
OPERATION 6: LOGICAL "NOT"

p	r
0	1
1	0

An operation of elementary algebra expressing this is $r = 1-p$, and a convenient operator is the prime ($'$), $p' = 1-p$.

But only the right-hand digit of the numbers 00, 01, 10, and 11 is needed to report the truth value of a statement. If the left-hand digit of this two-binary-digit number is also altered, 0 into 1 and 1 into 0, the result is the threes complement of the numbers 0, 1, 2, 3. Thus we can use the same designation "Operation 6" for both these operations, logical NOT and threes complement, as shown in Table 10.

TABLE 10
OPERATION 6: LOGICAL "NOT"; THREES COMPLEMENT

$r = T(\text{NOT-}P)$

p	r
0	1
1	0

$c = 3 - a$

a	a	c	c
0	0 0	3	1 1
1	0 1	2	1 0
2	1 0	1	0 1
3	1 1	0	0 0

If P and Q are two statements, then the statement "P or Q or both," also expressed as "P and/or Q," is true if and only if at least one of P and Q is true. This relation is expressed in Table 11 which covers all the possibilities:

TABLE 11
LOGICAL "OR"

P	Q	P OR $Q = R$
F	F	F
F	T	T
T	F	T
T	T	T

Replacing the indications T and F by 1 and 0, and rearranging the table, we have Operation 7, as shown in Table 12:

TABLE 12
OPERATION 7: LOGICAL "OR"

$r = T(P \text{ OR } Q)$

p \ q:	0	1
0	0	1
1	1	1

An operation of elementary algebra which gives r equal to 0 if p is 0 and q is 0, and 1 in the other three cases, is: $r = p + q - pq$. A convenient operator sign for designating this operation is the gothic v without serifs; we write $p \vee q = p + q - pq$. The v comes from the initial letter of the Latin conjunction "vel": Latin was in this respect richer than English, for it had two conjunctions "vel" meaning "and/or" (inclusive "or"), and "aut" meaning "or else" (the exclusive "or").

These three logical operations AND, OR, NOT included in Simon enable it to carry out a sequence of logical operations on statements. Simon could evaluate for example the truth value of an assertion like:

> If P implies Q, and NOT-Q or R is true, and R implies NOT-S, then S implies NOT-P.

In order for Simon to deal meaningfully with numbers larger than 3, it was necessary to provide for addition subject to carry. This was done by providing the arithmetic unit of Simon with a memory of one binary digit, which would record whether the previous addition gave rise to a carry or not. If the previous addition gave rise to no carry, then the arithmetic unit would put out the number $c = a + b$; if the previous addition gave rise to a carry, then the arithmetic unit would put out the number c plus 1. Table 13 defines the operation "addition subject to carry."

TABLE 13

OPERATION 8: ADDITION, SUBJECT TO CARRY

$c = a + b + p$

$p = T$(previous addition was $1+3$, or $2+2$, or $3+2$, or $3+3$).

p:	0	0	0	0	1	1	1	1
b:	0	1	2	3	0	1	2	3
a								
0	0	1	2	3	1	2	3	0
1	1	2	3	0	2	3	0	1
2	2	3	0	1	3	0	1	2
3	3	0	1	2	0	1	2	3

For example, Simon can perform the following addition which is written in the scale of 4:

13 (seven)
+23 (eleven)
102 (eighteen)

in the following manner:

(1) 3 plus 3 (regular addition without carry) is 6, take off 4, write down 2, and carry 1;

(2) 1 plus 2 (and now special addition with any carry, and there is a carry), is 4, take off 4, write down 0 and carry 1; finally

(3) 0 plus 0 (special addition with any carry, and there is a carry) is 1, which is less than 4, write down 1, and stop.

In a similar way, we need a second operation for finding the negative: "negation subject to carry." This is defined in Table 14.

TABLE 14
OPERATION 9: NEGATION, SUBJECT TO CARRY

$c = 3 - a + q(4p - 3)$

$p = T(a \text{ is } 1, 2, \text{ or } 3)$

$q = T(\text{previous negation without carry was of } 0)$

		q: 0	1
a	p		
0	0	3	0
1	1	2	3
2	1	1	2
3	1	0	1

Here is how this operation would be used. For an example, suppose we want to subtract 23 from 102 (both numbers written in the scale of 4):

$$\begin{array}{rl} 102 & \text{(eighteen)} \\ \underline{-23} & \text{(eleven)} \\ 13 & \text{(seven)} \end{array}$$

First, we find the negative of 023; this consists (in this case) of the fours complement of the last digit and the threes complement of the other two digits; so the negative of 023 is 311; then we add 311 to 102, dropping the last carry at the left, as is necessary when adding a complement,

$$\begin{array}{rl} 102 & \text{(eighteen)} \\ \underline{+311} & \text{(complement of eleven)} \\ (1)\ 013 & \text{(seven)} \end{array}$$

and we obtain for answer 13 as we should. Now in Simon, of course, the operation of subtraction is divided into two parts, finding the "negative" of the number to be subtracted and then adding it. The operation of addition we have already discussed. The operation of finding the negative applies then to the number 023; and is performed in the following way:

(1) the last digit *a* is equal to 3, and there was no previous nega-

tion; so *p* is 1, *q* is 1, and the digit of the negative is 1 according to the proper entry in the table;

(2) for the next digit *a* is 2, there was a previous negation, but not of the digit 0; so *p* is 1, *q* is 0 and the digit of the negative is 1;

(3) for the next digit *a* is equal to 0, and there was a previous negation but not of the digit 0; so *p* is 0 and *q* is 0, and therefore the digit of the negative is 3, according to the proper entry in the table.

And this gives us 311 equal to the negative of 102 which we require.

Codes

Now in order for Simon to be instructed to perform any operations, we must have codes for the operations and codes for the registers.

In the first stage of Simon, the codes for the four operations addition, negation, greater than, and selection were the four pairs of binary digits 00, 01, 10, and 11, respectively. After we decided that some more operations should be built into Simon, we assigned sets of four binary digits to designate the operations. These are shown in Table 15.

TABLE 15
OPERATION CODES

Operation No.	Operation Code	Operation Abbreviation	Operation
1	0000	Ad, n c	Addition, No Carry
2	0001	Neg, n c	Negation, No Carry; Fours Complement
3	0010	Gr	Greater Than
4	0011	Sel	Selection
5	0100	AND	Logical AND
6	0101	NOT	Logical NOT; Threes Complement
7	0110	OR	Logical OR
8	1000	Ad, w c	Addition, Subject to Carry from Previous Addition
9	1001	Neg, w c	Negation, Subject to Carry from Previous Negation

As mentioned before, Simon has 16 registers where numbers can be stored, each number consisting of two binary digits, and each register consisting of two relays. The list of registers and codes for the registers is shown in Table 16.

TABLE 16
REGISTER CODES

Register	Register Abbreviation	Register No.	Code
Input Register No. 1	IR1	1	0000
” No. 2	IR2	2	0001
Storage Register No. 1	SR1	3	0010
” 2	SR2	4	0011
” 3	SR3	5	0100
” 4	SR4	6	0101
” 5	SR5	7	0110
” 6	SR6	8	0111
Computer Register No. 1	CR1	9	1000
” 2	CR2	10	1001
” 3	CR3	11	1010
” 4	CR4	12	1011
” 5	CR5	13	1100
Output Register No. 1	OR1	14	1101
” 2	OR2	15	1110
” 3	OR3	16	1111

Programming

We are now ready to show how a calculation can be programmed and carried through on Simon. Not all of this will be fully understandable at first reading, because some of the information contained in Section V:4 about how Simon is constructed is quite useful for understanding the programming. But if anyone is seriously interested in Simon and its programming and construction, he will reread both discussions.

The operation of Simon is divided into cycles. Each cycle corresponds with one full turn of the stepper (a full turn, because of the construction of the stepper, means 180 degrees turn of the moving arm); the stepper makes the appropriate connections. In each cycle, the circuits are impulsed and do different things at ten different times, named 0 to 9. At time 2 in the cycle, Simon reads the information in the tape and is told what register should receive information in that cycle, in other words, what register should be connected to the bus to receive information. At time 5 in the cycle, Simon reads the tape again (it has been moved forward) and receives either a number or an operation from the tape. This number or operation may be of four binary digits, and is received in Input Registers No. 1 and No. 2. At time 8 in the cycle, Simon reads the tape a third time (it has again been moved forward) and is instructed what register should send information. Thus in every cycle Simon carries out the typical command of every automatic digital computer: "Transfer from register.... to register----."

The five computer registers are connected so that they operate in the following way:

1–Put numbers or information into Computer Registers No. 1, 2, 3.
2–In any cycle n, put an operation into Computer Register No. 4.
3–Then in the next cycle $n + 1$ the result is in Computer Register No. 5, and may be transferred into any other register.

The tape contains five holes; so far we have used four holes only for the designation of operations, numbers, and registers. These are the right-hand four holes. The fifth hole at the left may now be used for other purposes, and is so used in the following way: At time 2, a hole in the fifth place is used to clear Input Registers No. 1 and No. 2 so that they may receive information at time 5 in the same cycle. At time 5, this hole causes the tape to stop, and thus allow a number or operation to be inserted manually into Simon by means of the buttons on the front panel. At time 8, this hole stops the tape from running further through the machine.

One exception should be mentioned. The tape may be put into the tape feed at random, but then it must be synchronized with the stepper, so that when the stepper is at time 2, it "knows" that it is reading the first of the three commands in that cycle of the tape, and not the second or the third command. This is accomplished by an automatic synchronizing circuit which requires that there be no hole 5 in the first row on the tape; consequently a signal to clear input must not be given in the first row on the tape.

What about the clearing of other registers in Simon? There is an automatic resetting circuit for every other register in Simon which, as soon as a register is designated as one into which a number is to be entered, clears that register so that it is empty and ready to receive the new number.

In order to punch the five-hole tape, a manual tape punch is used. The keys of this tape punch show numbers 0 to 31 corresponding with the sets of binary digits 00000 to 11111. Three keys are depressed one after another to enter the three rows of punched holes which correspond with one cycle of Simon operations, one set of commands.

A summary of the rules for programming appears in Tables 15, 16, and 17.

TABLE 17
SIMON – CODING CHART

(Note: Each entry corresponds to one row of holes on tape. Each machine cycle of 10 times contains three entries.)

ENTRY 1 (at time 2):

Select Receiving Register *and Hold* Input Registers				Select Receiving Register *and Clear* Input Registers			
Register	Code	Key	Lights	Register	Code	Key	Lights
Storage 1	00010	2		Storage 1	10010	18	
Storage 2	00011	3		Storage 2	10011	19	
Storage 3	00100	4		Storage 3	10100	20	
Storage 4	00101	5		Storage 4	10101	21	
Storage 5	00110	6		Storage 5	10110	22	
Storage 6	00111	7		Storage 6	10111	23	
Computer 1	01000	8		Computer 1	11000	24	
Computer 2	01001	9		Computer 2	11001	25	
Computer 3	01010	10		Computer 3	11010	26	
Computer 4	01011	11		Computer 4	11011	27	
Output 1	01101	13	16	Output 1	11101	29	16
Output 2	01110	14	8,4	Output 2	11110	30	8,4
Output 3	01111	15	2,1	Output 3	11111	31	2,1

(Note: In order for the tape to synchronize automatically, there must be no hole 5 in the first row on the tape. Consequently, a signal to clear input must not be given in the first row on the tape.)

ENTRY 2 (at time 5): Number or Operation to be received by Input Registers 1 and 2

Number	Operation	Code	Key
0	Add, with no previous carry	00000	0
1	Negate, with no previous carry	00001	1
2	Greater than	00010	2
3	Selection	00011	3
4	Logical AND	00100	4
5	Logical NOT; 3's Complement	00101	5
6	Logical OR	00110	6
7	(not used)	00111	7
8	Add, with previous carry	01000	8
9	Negate, with previous carry	01001	9
10	(not used)	01010	10
11	”	01011	11
12	”	01100	12
13	”	01101	13
14	”	01110	14
15	”	01111	15
—	Stop for manual inserts	10000	16

(Note: Input Register 1 receives from holes 1 and 2; IR2 receives from holes 3 and 4; an operation read into IR1 and 2 can be transferred as a four binary digit number into Computer Register 4. All other transfers are two binary digit numbers.)

ENTRY 3 (at time 8):

Sending Register Selected,
no machine stop;

Register	Code	Key
Input 1	00000	0
Input 2	00001	1
Storage 1	00010	2
Storage 2	00011	3
Storage 3	00100	4
Storage 4	00101	5
Storage 5	00110	6
Storage 6	00111	7
Computer 1	01000	8
Computer 2	01001	9
Computer 3	01010	10
Computer 4	01011	11
Computer 5	01100	12
Output 1	01101	13
Output 2	01110	14
Output 3	01111	15

Sending Register Selected;
Machine *Stop*!

Register	Code	Key
Input 1	10000	16
Input 2	10001	17
Storage 1	10010	18
Storage 2	10011	19
Storage 3	10100	20
Storage 4	10101	21
Storage 5	10110	22
Storage 6	10111	23
Computer 1	11000	24
Computer 2	11001	25
Computer 3	11010	26
Computer 4	11011	27
Computer 5	11100	28
Output 1	11101	29
Output 2	11110	30
Output 3	11111	31

Sample Problems

Suppose now that we wish to program Simon so that it will add 2 and 1 and obtain 3. Let us call this Problem 1. The programming to be entered on the tape for Problem 1 is shown in Table 18.

TABLE 18

PROBLEM 1 – ADDING ONE AND TWO

Cycle	Instruction	Codes to be Punched	Keys to be Pressed		
1	Synchronize	00111 00000 00000	7	0	0
2	Clear input; put two into I 1; transfer into C 1	11000 00010 00000	24	2	0
3	Clear input; put one into I 1; transfer into C 2	11001 00001 00000	25	1	0
4	Clear input; put addition into I 1; transfer into C 4	11011 00000 00000	27	0	0
5	(Clear input); transfer the result (three) from C 5 into O 3, so that it will show in Output Lights 1 and 2; and stop	11111 00000 11100	31	0	28

But this problem is not too interesting for demonstration purposes, for all a member of the audience can see is that when the tape has run through and the machine stops, two of the five output lights shine, designating 00011, or three, for the answer. For all that this bystander knows, something else than the process of adding 2 and 1 has caused these two lights to both shine.

Let us consider therefore a second problem, in which a member of the audience gives the machine two numbers to add, choosing them between 0 and 15. This has the advantage that it is impossible to predict beforehand what numbers the bystander will choose, so that the answer must be computed by the machine. The coding for this problem is shown in Table 19.

Another problem which we have programmed for Simon and which proves to be interesting to an audience is the Greater-Equal-Less Problem, which is as follows:

> Manually insert two numbers *A* and *B* between 0 and 15. Have Simon report by shining a light in Register O 1 if *A* is less than *B*, in Register O 2 if *A* equals *B*, and in Register O 3 if *A* is greater than *B*.

Two more problems which have been programmed for Simon are multiplication and division. The history of their programming is worth noting. On an occasion when Simon was being exhibited for several days at Wayne University in Detroit, a member of the audience (Keith R. Symon) looked over the coding examples that had been spread out on the tables. Then he sat down, wrote out a program for multiplying two numbers chosen in the range 0 to 3, punched out the tape, and it ran successfully. Some time later Simon was borrowed by a high school boy (Ivan Sutherland) to be shown to classmates in his high school in Scarsdale, New York. He returned the machine together with a new tape worked out for long division, and a new circuit installed for stopping the machine when it had determined the answer, which in some instances occurred much sooner than in others.

These experiences confirm the original purpose of Simon, to make it possible for people to work with a simple little automatic computer, and learn more in one hour working with the machine than they could learn in twenty hours with just words and paper. They also confirm that Simon is a completely general automatic computer although with very limited capacity to store information. If the storage capacity were increased, all the computing one could ordinarily wish to do, even if only slowly, could be done by the computing circuits in Simon.

One more remark: it would of course have been possible to write this whole section on operations and programming using not Simon as an illustration but an existing large automatic digital computer that does useful work. This would, however, make the section a good deal longer and more complicated, and for purposes of instruction and training, probably less clear. After all, one learns to solve a linear equation like $7x + 14 = 0$ before dealing with equations of higher degree.

TABLE 19

PROBLEM 2 – ADDING TWO NUMBERS BETWEEN 0 AND 15

This program tape takes in two numbers *A* and *B* from 0 to 15, manually inserted at the first two stops, and reports in lights at the end, the total from 0 to 30.

Cycle	Instruction	Keys		
1	Synchronize	7	0	0
2	I 1 to O 3 (Clear input and check that no lights go on)	31	0	0
3	I 1 into C 1 (Manual insert of A, all into I 1 and I 2, and transfer right half into C 1)	24	16	0
4	I 2 into S1 (Left half of A)	2	0	1
5	I 1 into C2 (Manual insert of B, all into I 1 and I 2 and transfer left half into C1)	25	16	0
6	I 2 into S2 (Left half of B)	3	0	1
7	(Adn, no carry) I 1 and I 2 into C4	27	0	0
8	C5 into S3 (Right two digits of result)	20	0	12
9	S1 into C1	24	0	2
10	S2 into C2	25	0	3
11	(Adn, with carry) I 1 and I 2 into C4	27	8	0
12	C5 into S4 (Next two digits of result)	21	0	12
13	I 1 into C1 (Zero)	24	0	0
14	I 1 into C2 (Zero)	25	0	0
15	(Adn, with carry) I 1 and I 2 into C4	27	8	0
16	C5 into O1 (Fifth digit of result, in lights)	29	0	12
17	S4 into O2 (3rd and 4th digit in lights)	30	0	5
18	S3 into O3 (1st and 2nd digits in lights, and stop)	31	0	20

V:4 HOW SIMON IS CONSTRUCTED

Earlier we said that there were five sections to every automatic computer: input, output, storage, computing unit, and control unit. Exactly what are these various sections in Simon? And how are they assembled from hardware in such a way as to make a complete, functioning, automatic computer?

Relays

In Simon, the functions of storage, computing unit, and control unit are carried out by relays. In addition, input information as soon as it is taken into the machine, and output information ready to be given to the output lights, are expressed in relays. Basic to an understanding of Simon, therefore, is an understanding of the functions of its relays.*

Figure 43 is a diagram showing all the 129 relays in Simon, locating them in the same relative position that they are in the machine. Two kinds of lines are used in this diagram. The thin black lines outline small squares standing for relays. Nearly all these squares contain an abbreviation expressing the function of the relay. If any square is blank, containing no abbreviation, it is electrically in parallel with and has the same function as the relay designated at its left, and its purpose is simply to provide more contacts for circuits requiring that function. The thick black lines in the diagram show certain relays which may be grouped together as having the same function; for example, the six pairs of relays marked SR are grouped together and jointly labeled STORAGE (which is their function).

This diagram may be compared with the photograph of the machine shown in Figure 40. Each small square in the diagram corresponds with a relay shown in the photograph; and 19 columns (designated by numbers) and 8 rows (designated by letters) appear in both the diagram and the photograph. For wiring purposes each relay must be designated by column, number, and row letter, so that the wireman knows from its spatial position alone which relay terminal is to be wired to which relay terminal. But for understanding the operation of the machine, functional designations are much more useful.

The functional designation of each relay is shown in the body of the diagram (not at the edges), and is an abbreviation that may

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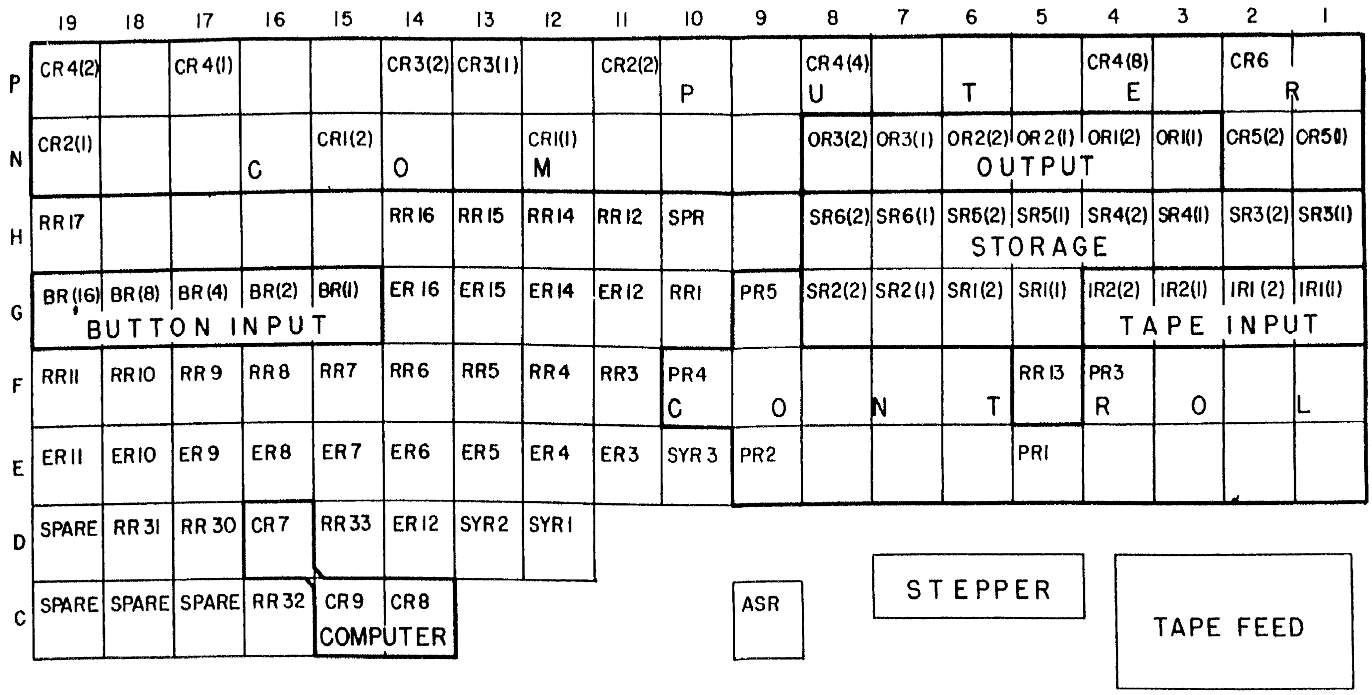
*For definition and explanation of a relay, a pick-up coil, energizing a relay, a transfer contact, a normally closed contact, a normally open contact, the graphic representation of a relay and relay contacts in circuits, diagrams, and similar information, see "Giant Brains", *op.cit.*, pp. 20 to 36.



Courtesy *"Radio Electronics"; Copyright 1950-51 by Gernsback Publications, Inc.*

Figure 43. Plan of top of Simon.

have three parts. Part 1 consists of two or more letters, which specify the kind of relay; there are 11 kinds and they are shown in Table 20. Part 2 of the abbreviation, if any, is a number used to number consecutively registers or relays all of the same kind. Part 3, if any, is a number in parentheses, used to tell the binary digit being handled by that relay. For example, SR3(2) (see the relay in Row H, Column 2) is a functional designation that reports: SR for Storage Register; 3 for No. 3, the third storage register; and 2 for the binary digit in the two's column. If 16, 8, 4, or 1 appeared, it would report binary digits in other columns of a binary number. The functions of the relays are given even more specifically in Table 21.

TABLE 20
SIMON – RELAY FUNCTIONS – GENERAL

Abbreviation	Name	Purpose
ASR	Auxiliary Stepping Relay	Slow down the stepping switch.
BR	Button Register	Temporarily record numbers or operations or instructions from buttons.
CR	Computer Registers	Compute
ER	Entrance Relays	Allow information to enter registers.
IR	Input Registers	Hold numbers or operations received from the tape or the buttons.
OR	Output Registers	Hold answers, to be shone in the output lights.
PR	Program Relays	Record instructions from the tape or from the buttons, and control Simon.
RR	Reset Relay	Reset, release, or clear registers, so that new information may be stored in them.
SPR	Step-Position Output Relay	Allows the position of the stepping switch to be read in the output lights.
SR	Storage Registers	Store information until used.
SYR	Synchronism Relays	Arrange that the tape and the machine cycles shall be automatically in synchronism.

TABLE 21

SIMON – RELAY FUNCTIONS – SPECIFIC

Location Designation	Description	Functional Designation
C2	Tape coil relay	TCR
C9	Auxiliary stepping relay	ASR
C14	Negation carry relay	CR8
C15	Negation subcarry relay	CR9
C16	Negation carry release relay	RR32
C17 to C19	Spares	–
D12 and D13	Automatic tape synchronization relays	SYR1, SYR2
D14	Extra entrance relay for CR4 register	ER12
D15	Release relay for CR4(8) and CR4(4) relays	RR33
D16	Addition subcarry relay	CR7
D17	Addition subcarry release relay	RR30
D18	Addition carry release relay	RR31
D19	Spare	–
E1 to E5	Program Relay #1 (First binary digit on tape)	PR1
E6 to E9	Program Relay #2 (Second binary digit on tape)	PR2
E10	Tape Synchronization Alarm Relay	SYR3
E11 to E19	Entrance Relays	ER3 to 11
F1 to F4	Program Relay #3 (Third binary digit on tape)	PR3
F5	Prevents back circuits in CR5, closes at Time 8 only	RR13
F6 to F10	Program Relay #4 (Fourth binary digit on tape)	PR4
F11 to F19	Release Relays	RR3 to 11
G1 to G2	Input Register 1	IR1
G3 to G4	Input Register 2	IR2
G5 and G6	Storage Register 1	SR1
G7 and G8	Storage Register 2	SR2
G9	Program Relay #5 (Fifth binary digit on tape)	PR5
G10	Input Registers' Release Relay	RR1
G11 to G14	Entrance Relays	ER12 to 16
G15 to G19	Button Input Relays	BR
H1 and H2	Storage Register 3	SR3
H3 and H4	Storage Register 4	SR4
H5 and H6	Storage Register 5	SR5
H7 and H8	Storage Register 6	SR6
H9 and H10	Select-Output-Lights-or-Time-Lights Relays; Operates from TS5	SPR
H11 to H14	Release Relays #12 to #16	RR12, 14 to 16
H15 to H19	Prevent back circuits in release relay circuits	RR17
N1 and N2	Computer Register 5 (Computed answers appear here)	CR5

Location Designation	Description	Functional Designation
N3 and N4	Output Register #1 (Output light only on 1st binary digit)	OR1
N5 and N6	Output Register #2	OR2
N7 and N8	Output Register #3	OR3
N9 to N15	Computer Register 1	CR1
N16 to N19	Computer Register 2 (First binary digit)	CR2
P1 and P2	Add carry relay	CR6
P3 and P4	Operation register (Fourth binary digit)	CR4(8)
P5 to P8	Operation register (Third binary digit)	CR4(4)
P9 to P11	Computer Register 2 (Second binary digit)	CR2
P12 to P14	Computer Register 3	CR3
P15 to P19	Computer Register 4 (Operations put in this register)	CR4

Registers, Codes, Entrance Relays, and Reset Relays correspond as follows:

Register	Code	Entrance Relay	Reset Relay
IR1	0000	none	RR1
IR2	0001	none	RR1
SR1	0010	ER3	RR3
SR2	0011	ER4	RR4
SR3	0100	ER5	RR5
SR4	0101	ER6	RR6
SR5	0110	ER7	RR7
SR6	0111	ER8	RR8
CR1	1000	ER9	RR9
CR2	1001	ER10	RR10
CR3	1010	ER11	RR11
CR4	1011	ER12	RR12
CR5	1100	none	RR12
OR1	1101	ER14	RR14
OR2	1110	ER15	RR15
OR3	1111	ER16	RR16

In Simon there are six registers, sets of relays which hold meaningful information as such. These are: BR, the Button Relays or Manual Input Register; IR, the Input Registers or Machine Input Registers; SR, the Storage Registers; CR, the registers of the Computing Unit; OR, the registers of the Output Unit; and PR, the relays that register the program or instruction.

Having identified the relays and registers which are used in Simon to store and manipulate information, we are now ready to describe more fully the five fundamental sections of the machine: input, output, storage, computing unit, and control unit.

Input

The input of Simon consists of five-hole paper tape, the tape feeding mechanism, switches, buttons, and the relay registers BR and IR. BR, the Button Register or Manual Input Register, is a single register consisting of five relays, which receive numbers or operations or instructions by pressing buttons on the input panel. IR, the Input Registers or Machine Input Registers, consists of two registers of two relays each, which receive numbers or operations either from the Button Register or from the tape.

Ordinarily, for carrying through a problem on Simon, you place all the instructions and operations on punched tape, using the method of programming described in Section V:3, and provide that the numbers will be manually inserted by pushing buttons at certain times. When Simon stops to receive a number, you press any one or more of the buttons numbered 8, 4, 2, 1. This accepts the number that is the sum of the figures selected, and places that sum into the BR register as a binary number. The number must now be transferred into the Machine Input Relays, the IR registers: so you press the red button on the front of the machine marked "Button Input" and this transfers the number from BR to IR. Then, you press the button marked "Stepper Jog," and Simon again runs ahead automatically reading and obeying the tape.

If the machine is being operated manually and not automatically, it is necessary to insert instructions also. These are inserted into the Button Relays, the Manual Input Register, by means of the same push buttons as before, and again transferred into the automatic part of the machine by pressing the red button marked "Button Input." But depending on the time in the machine cycle, an instruction is inserted into the PR relays, the Program Register, instead of a number or an operation into the IR relays.

Clearing of the manual input registers takes place automatically three times each cycle. Clearing of the machine input registers, however, is programmed by means of the fifth hole in the program tape, punched so that it will be read at time 2. Otherwise the machine input register holds its information until power is turned off, which causes all relays to drop out.

Output

The output of Simon shows on the front panel. It consists of five lights called output lights 16, 8, 4, 2, 1, and relays associated with these lights, the relays of the Output Registers, OR1, OR2, and OR3. In these lights any number from 0 (no lights shining) up to 31 (all lights shining) may be indicated. For example, if output lights 16, 4, and 1 are shining, the number indicated is 16 plus 4 plus 1, or 21.

OR, the Output Registers, consist of three registers, OR1 to OR3, having two relays each. Five of these six relays are connected to the five output lights. Whenever the relays of the output registers contain information, the output lights will shine, in accordance with the following correspondence:

OR1 (1)	Light 16
OR2 (2)	Light 8
OR2 (1)	Light 4
OR3 (2)	Light 2
OR3 (1)	Light 1

Simon is usually programmed so that it will stop when a result has been delivered. Then you have the necessary time to examine the lights, and note the result; and afterwards you press the stepper jog button and Simon will run on. In a case where a number of ten binary digits is being reported as an answer by the machine, the program will provide that, say, the right-hand half first, and then the left-hand half, will be delivered to the output lights to be read.

Storage

The storage of Simon consists of six registers of two relays each. These are designated SR and numbered from 1 to 6. During the course of a calculation they hold information and provide it when desired. When a storage register is designated to receive information, the entrance relay associated with it is energized, and connects the pickup coils of that register to the bus; thus that register only will receive information as it flows along the bus.

The same impulse that picks up the entrance relay of a storage register preparing it to receive information also energizes the release relay for that register, clearing it so that it can take in new information. When a register is designated to transmit information, no relay needs to be energized because rectifiers are used between the register and the bus in such a way that electric signals will flow only out of the register.

Computing Unit

The computing unit of Simon, or more briefly its computer – using the word in a second meaning to designate those circuits that are directly concerned with calculating – consists of CR, the computer registers. CR1, CR2, and CR3 take in numbers, and will hold two binary digits each; CR4 takes in an operation and will hold four binary digits; and CR5 is the computer result register and will hold two binary digits. CR6, 7, 8, and 9 hold carry information under various conditions; they are not accessible directly to the computer but only indirectly as a result of operations going on in the computing unit.

Figure 44 shows the actual computing circuits for four of the operations in Simon – addition without carry, logical AND, NOT, and OR. In this figure the block diagram containing N stands for a network of relay contacts which select the result; they are therefore a network of the contacts of the CR4 relays which store the operation. In other words, all the operational results are established by the computer at each cycle, and the CR4 relays select the result that the computer is to yield at that cycle.*

Clearing of the registers CR1, 2, and 3 takes place whenever a new operation is put into the CR4 register. This enables the computer to hold information from one cycle to the next until it has all the information that it needs in order to compute, i.e., rearrange its relay contacts.

Control

The control of Simon is accomplished mainly by transferring information from the tape into the program relays, PR, and using the configuration of the PR relay contacts to select a receiving register and a sending register in each cycle.

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*See the sample of selecting contacts in the figures in "Giant Brains," *op.cit.*, pp. 36 to 38.

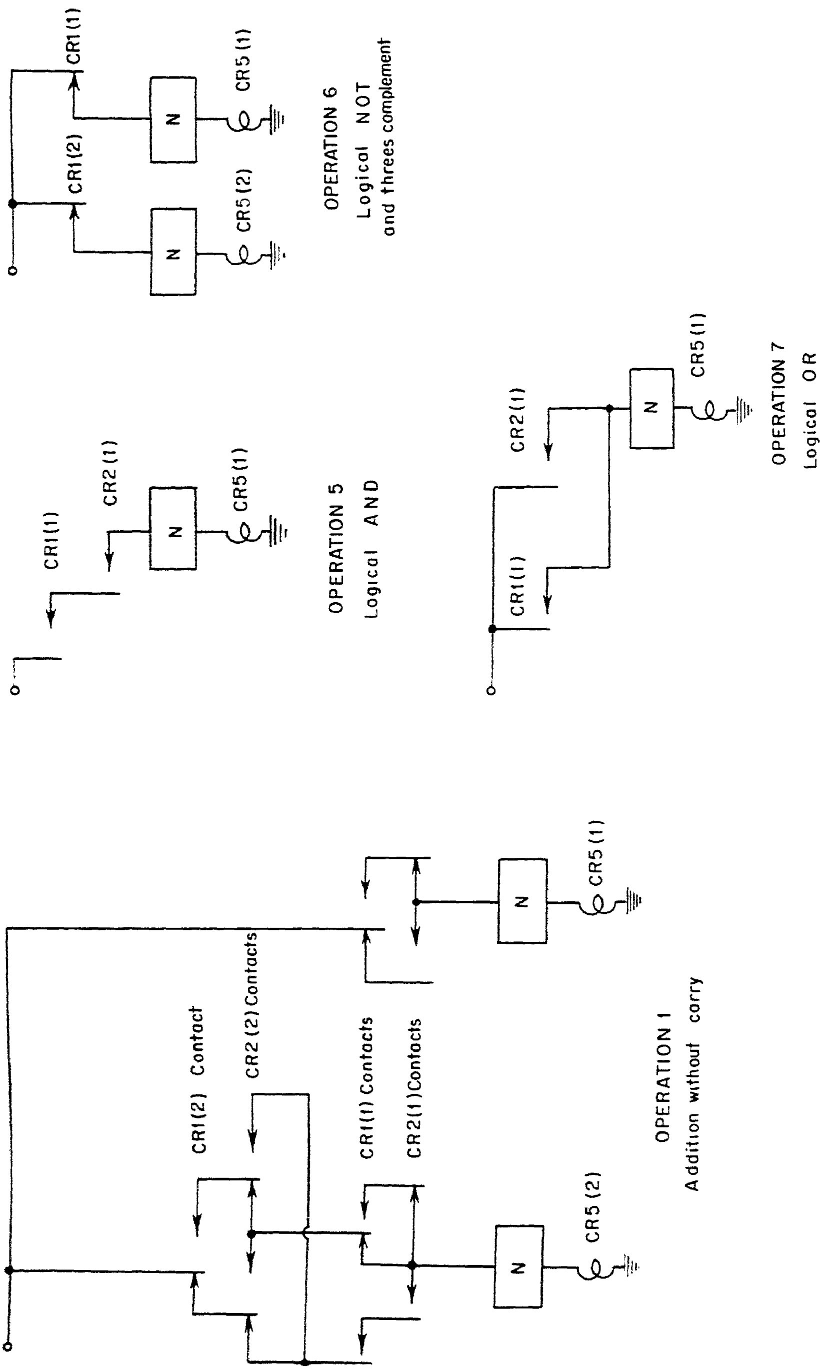
CR1(1)
CR1(2)
N
N
CR5(1)
CR5(2)
OPERATION 6
Logical NOT
and threes complement
CR1(1)
CR2(1)
N
CR5(1)
OPERATION 5
Logical AND
CR2(1)
CR1(1)
N
CR5(1)
OPERATION 7
Logical OR
CR1(2) Contact
CR2(2) Contacts
CR1(1) Contacts
CR2(1) Contacts
N
N
CR5(2)
CR5(1)
OPERATION 1
Addition without carry

Figure 44.

PR, the Program Relays, consist functionally of five relays PR1 to PR5, one corresponding with each of the five holes across the tape. Actually each of these relays has other relays in parallel with it in order to furnish enough contacts. Twice in each cycle they are picked up through the holes in the tape, and twice in each cycle their contacts are controlling the machine. The codes inserted in the tape determine the configuration of program relays energized.

Essential Circuits

We have now explained the terms *input, output, storage, computing unit,* and *control* in terms of a particular set of relays that actually performs that function. What, then, is the general scheme, the overall circuit wiring, whereby this equipment works as a complete automatic computer? This may be seen in Figure 45 which shows sketchily and schematically the ten essential circuits of Simon, beginning with moving the tape and ending with putting information out in the output lights.

Let us go down through this chart and examine it. Circuit 1, the Tape Moving Circuit, shows just one relay called the *Tape Moving Relay.* This is contained in the tape feed mechanism; it is a big relay which pulls down the metal fingers, moves the tape from one position to the next, and pushes the fingers up again. Circuit 2, the *Program Relay Pickup Circuit,* represents the five metal fingers of the tape feed, feeling upwards against the paper tape; one of the fingers finds a hole and projects, touching the metal terminal or tape feed bus, causing the PR2 relay to become energized. Circuit 3, the *Reset Connect Pickup Circuit,* shows that RR17, one of the reset relays, is picked up at certain times for purposes that will become clear later. Circuit 4, the *Select (and Reset) Receiving Register Circuit,* shows two sets of relays, entrance relays ER and reset relays RR, which are picked up through a branching network of program relay contacts. Because of the times of operation written next to the T terminals, we can see that at time 2 the entrance relay for some register is picked up, but that the corresponding release relay clearing it is picked up only at time 4 by means of current from T11 through the hold contact of the energized ER relay. This roundabout way had to be worked out to avoid back circuits. Circuit 5, the *Input Reset Circuit,* picks up one relay, RR1, by means of a contact on

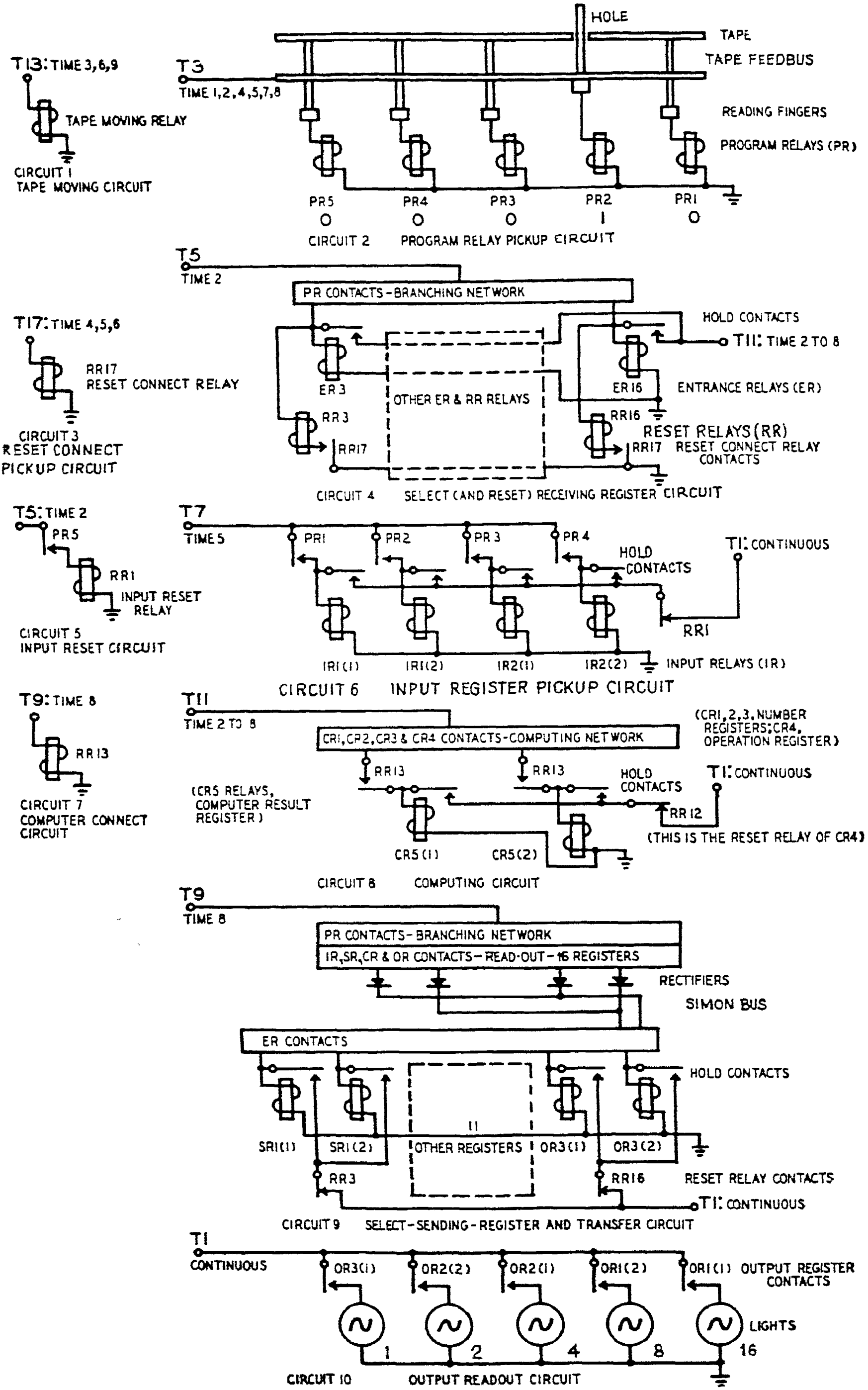

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Figure 45.

PR5, provided it is energized at time 2. Circuit 6, the *Input Register Pickup Circuit,* shows that contacts on the PR relays are used to energize the IR relays; the time, however, is time 5, and there is no conflict with the use of other PR information in different ways at times 2 and 8 (see Circuits 4 and 9). Only when relay RR1 is energized, is there no current going to the hold contacts, and the input relays drop out. (In this chart of the ten essential circuits of Simon, the energizing of the input relays from the button relays is not shown.) Circuit 7, the *Computer Connect Circuit,* shows that relay RR13 is energized at time 8 only. Circuit 8, the *Computing Circuit,* shows that by means of a network of contacts of the CR1, 2, 3, and 4 relays, the computer result register CR5 is energized. But it can only be energized through the contacts of relay RR13, and thus only at time 8. CR5 is held up continuously except when reset by the energizing of RR12, which is energized in accordance as one of the RR relays in Circuit 4. Circuit 9, the *Select Sending Register and Transfer Circuit,* is probably the main circuit in the machine. Through a network of contacts of the PR relays, energy is fed to just one of the 16 registers of the machine, then to the read-out contacts of its relays, then through rectifiers into the bus (the Simon bus, consisting of two wires), then through the ER contacts of a selected receiving register into its pickup coil. The information once inserted is held by continuous current, which may be interrupted when the reset relay for that register is energized. Finally, Circuit 10, the *Output Readout Circuit,* shows that contacts of five of the output register relays lead to shining of the output lights.

Timing Of The Machine

For Simon to operate, actions have to happen successively in precise timing. The timing is done by a stepping switch with six levels, and effectively ten timing points. Nine are used; one is not used. The stepper has bridging wipers, so that uninterrupted current for holding up relays can be provided. The various levels and timing points are wired in such a way as to give seven terminals identified as T3, T5, T7, T9, T11, T13, and T17 (see Figure 46), which provide currents at different times.

The way in which these timed currents are used to energize the relays and circuits of Simon is shown systematically in the Timing

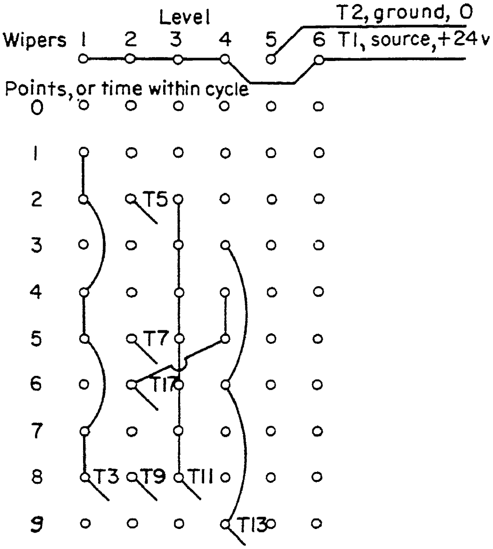

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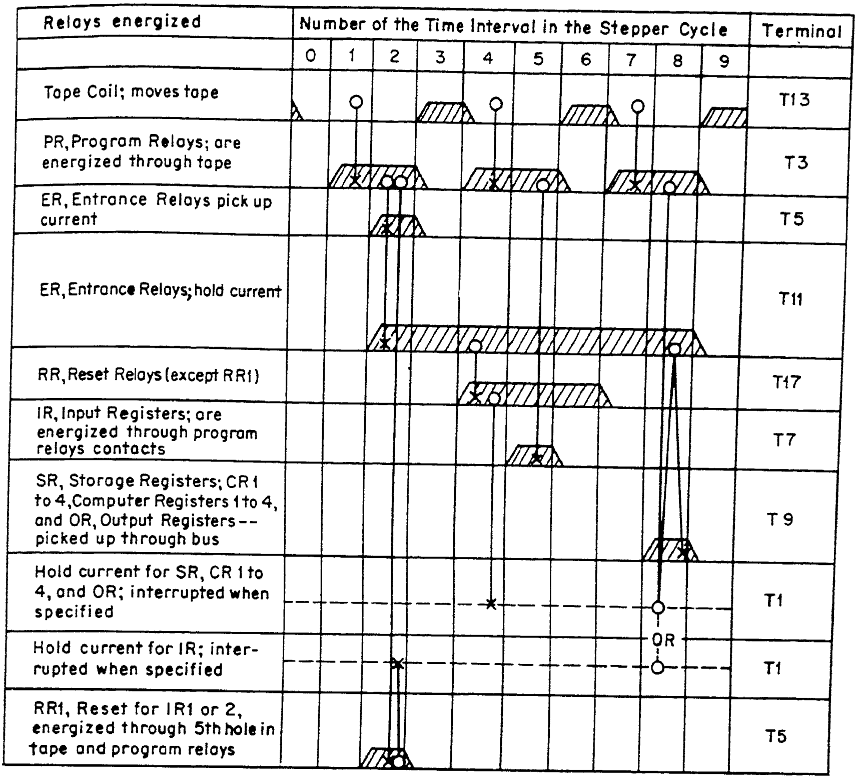
Figure 46. How the six-level stepping switch that activates the relay banks is wired.

Chart shown in Figure 47, where most of the operation of the machine is indicated. Let us now go through the timing chart, considering the ten essential circuits of Simon, to see better still how the machine operates as an automatic computer.

At time 1, there is an 0 on the first row, and an X on the second row, and a vertical line connects them. This means that at time 1, we read through holes in the paper tape (which at this time is still) and pick up the corresponding program relays (see Circuit 2 in Figure 45). At time 2, similarly interpreting the vertical line, we read through the positioned contacts of program relays to select the receiving register, and pick up its entrance relay, which is held up until time 8 (see circuit 3). We also optionally (if there is a hole in position 5 on the tape) pick up RR1 (reset relay No. 1), which action resets the input register by interrupting its hold current (see Circuits 5 and 6). At time 3, all that happens is that we move tape (see Circuit 1), and drop out the program relays. At time 4, we read through tape again and pick up the program relays once more, for they are the relays in which the information from the tape is always immediately placed (see Circuit 2). Also at time 4, we read through the hold contact of the selected entrance relay and pick up the corresponding reset relay, which resets the receiving register by


Relays energized
Number of the Time Interval in the Stepper Cycle
Terminal
0
1
2
3
4
5
6
7
8
9
Tape Coil; moves tape
T13
PR, Program Relays; are energized through tape
T3
ER, Entrance Relays pick up current
T5
ER, Entrance Relays; hold current
T11
RR, Reset Relays (except RR1)
T17
IR, Input Registers; are energized through program relays contacts
T7
SR, Storage Registers; CR 1 to 4, Computer Registers 1 to 4, and OR, Output Registers -- picked up through bus
T9
Hold current for SR, CR 1 to 4, and OR; interrupted when specified
T1
OR
Hold current for IR; interrupted when specified
T1
RR1, Reset for IR1 or 2, energized through 5th hole in tape and program relays
T5

O The contacts are read through.

X The coils are energized.

Figure 47.

interrupting its hold current (see Circuits 3 and 4). At time 5, we read through contacts of the program relays and pick up the input registers 1 and 2, storing there a number or operation (see Circuit 6). At time 6, we move tape and drop out the program relays. At time 7, we read through holes in the paper tape and pick up the program relays once more (see Circuit 2), this time to select the sending register.

At time 8, we transfer information (see Circuit 9). We read through, from the source:

1—contacts of the program relays which select a sending register (these relays were energized at time 7);

2—contacts of that sending register (held up by continuous current);

3—the bus;

4—the contacts of the receiving register's Entrance Relay (which have been closed and have been held from time 2 to 8);

5—and the coils of the selected receiving register, to ground.

And at time 9, we move tape preparatory to the next cycle, and drop out the program relays and entrance relay.

Independently of this main sequence of events, computing takes place in Circuit 8. The computer consists of three registers CR1, CR2, CR3 which take in numbers, and a fourth register CR4 which takes in an operation. Suppose that on previous cycles, these registers have been filled with the desired information, and that CR4 is the last one so filled. Then by means of T11, current is passed through the contacts of those four registers. To avoid back circuits, however, the computer is connected only at time 8 to the fifth computer register, CR5, which stores results (see Circuits 8 and 7).

Conclusion

This brings us to the end of the present discussion of Simon, and its construction. Probably enough has been set down here so that the way in which equipment is put together to make a functioning automatic computer is fairly clear. Would it be possible to make a still smaller automatic computer? Yes. Could it be made so small and so cheap and so simple that it could be bought and put together by an ordinary person in ten hours? Perhaps, although whether it would still be large enough to be interesting would be a question.

What about a miniature electronic computer, using a magnetic drum, tubes, and other devices more modern than relays? Certainly a miniature automatic computer of this type is also possible, and will probably be constructed before long. It would be much more useful than a miniature relay computer in some respects because of its closer correspondence with more modern automatic computers, but it would be harder to make it operate reliably, and harder to understand it, because relays excel in reliability and simplicity. Whether the plans and the rights to construct it can be easily acquired is an open question.

SECTION VI

SOME LARGE-SCALE AUTOMATIC DIGITAL COMPUTERS

VI:1 UNIVAC

One of the large, high speed, automatic digital computers is Univac. This machine is produced by the Eckert-Mauchly Division of Remington Rand, Inc., Philadelphia, Pa. The first completed Univac was accepted by the Bureau of Census in March, 1951; and by the beginning of 1955, more than 25 had been delivered to various users or were on order.

The purpose of Univac is to provide rapid, accurate, and versatile data processing and computing for both scientific and business applications. There are two models, Univac I and Univac II. The information given here applies only to Univac I. Univac II will be ready in 1956-57, and some description of it is given at the end of this discussion.

The System as a Whole

A layout of the computing system as a whole is shown in Figure 48. It consists essentially of the following units:

1—A "Central Computer," which processes information.

2—One to ten "Uniservos," which are devices which read and write on magnetic tape at high speed.

3—A "Supervisory Control Console," which is used by the operator to guide the machine. Associated with the console is a keyboard for entering information directly into the computer and a printing unit for taking out information directly from any part of the computer.

4—Printing units, consisting of: (a) the "High-Speed Printer" operating at speeds of 600 printed 130-column lines per minute and (b) one or more "Uniprinters," electric typewriters adapted to convert information recorded on magnetic tape to typewritten form.

5—One or more "Unitypers," which accept key strokes on the keyboard of a modified electric typewriter and record characters directly on magnetic tape in binary code.

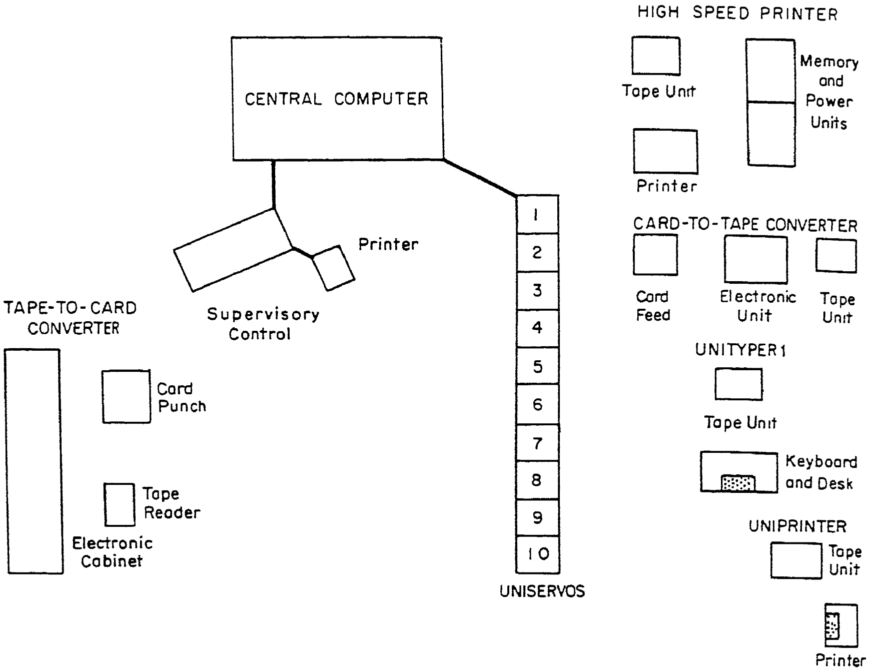


Figure 48. Possible layout of a Univac System.

6—A "Card-to-Tape Converter," which reads information from punch cards and records the information on magnetic tape in binary code at the rate of 240 punch cards per minute.

7—A "Tape-to Card Converter," which reads the information recorded on magnetic tape and punches the information on punch cards at a rate of 120 cards per minute.

In a typical installation, the floor space required is about 3500 square feet for working space and about 400 square feet for refrigeration. The central computer group, including power supply, supervisory control, Uniservos, and printer dolly, requires approximately 1000 square feet. For purposes of moving, the central computer can be divided into panels. The two largest sections, the roof and the floor, are 14 feet by 8½ feet by 14 inches but may be taken apart if necessary. Assembled, the central computer is about 14 feet long, 8 feet wide, and 8½ feet high.

The machines operate internally in a modified binary system, which may represent 64 different characters. Each character is expressed within the machine by a pattern of six binary digits (with a seventh binary digit for checking). The seventh binary digit is a check digit used to make the total number of binary ones in the character an odd number. Of the 64 characters, 63 are used, to designate letters of the alphabet, digits, punctuation signs, and miscellaneous symbols.

An information word is 12 characters long; a space one character wide occurs between information words; and accordingly a machine word, which includes the intervening word-space, is 13 characters long or 91 binary digits long. If a word contains alphabetic information, it is equivalent to 72 binary digits; but if it contains numeric information, it is equivalent to 11 decimal digits plus the algebraic sign, or approximately 45 binary digits. A word may also contain two machine instructions, and each is half a word in length, or six digits long.

The basic pulse rate of the computer is 2.25 megacycles. The time from one pulse to the next is accordingly 0.44 microsecond; this is called one pulse period, or one pulse time, or one bit time.

Memory

Mercury Delay Lines

The total rapid memory of Univac I consists of seven tanks of mercury and is known as a mercury delay line memory (see p. 227 for information on the magnetic core memory in Univac II). Each tank contains 18 paths or channels, along which a pattern of pulses can be remembered, or stored, as a circulating train of waves. The 126 channels are allocated as follows: 100 for main memory; 7 for temperature control (1 in each tank); 6 for input from Uniservos (known as the I register or I tank); 6 for output to Uniservos (known as the O register or O tank); 6 as spare channels; 1 for the so-called "ten-word transfer" or "Y register" operations.

Each of these channels is capable of storing ten words, each equal to 12 characters, or 720 binary digits (together with 120 check bits in addition). Consequently, this portion of the rapid memory of the computer consists of 1000 "registers" of mercury tank memory, totaling 720,000 binary digits (plus checking bits).

The access time to any register ranges from 40 to 404 microseconds, depending on the number of words, from 0 to 9, which must circulate before the desired word arrives in the train of waves. The average access time is, accordingly, 222 microseconds.

Magnetic Tape

The slow memory of Univac is magnetic tape. The tape is made of nonmagnetic metal and coated with a magnetic substance. It travels past the Uniservo reading head at a maximum speed of 100 inches per second. To reduce wear and tear, a thin strip of slippery plastic known as Mylar is placed between the tape and the head. The tape is one-half inch wide and contains eight channels. Of these channels six hold information, the seventh holds the check bit, and the eighth (for technical reasons) is a sprocket or positioning channel.

The tape will start from rest, go to full speed, record or read a block of 720 characters, and then stop again, in a total of 104 milliseconds. The machine can automatically refer to 10 reels of 1500 feet each. As the tape runs, it regularly stops and starts between every two consecutive blocks. Accordingly, the instantaneous rate of reading or recording on magnetic tape is 12,850 characters per second, and the long-run rate is 7200 characters per second. This rate is equivalent, for example, to reading or punching all 80 columns of 120 punch cards every second.

These data combine to give 1.2 million registers of slow memory, and 86 million binary digits of slow memory. But since the reels may be changed and replaced, there is hardly any limit to the external memory.

Any part of the slow memory may be rapidly called into position and connected with the rapid memory, whenever desired. Only the instruction to initiate read-in or read-out on a specified reel (Uniservo) from 1 to 10 requires computer calculating time; in all the remaining time during which information is read from tape or recorded on tape, the central computer can continue calculating without interference.

Arithmetic Unit

The average number of three-address operations per second using words of 11 decimal digits and algebraic sign (or 12 alpha-numeric characters) is:

Addition or subtraction	710
Multiplication	330
Division	210
Comparison	800

These figures represent averages; they do not show the actual range of speed. The rate of performing comparisons, for example, ranges from 500 to 1100 per second.

All of the above rates depend for the most part on the amount of time spent waiting for the required operands to be drawn out from their circulating pulse trains in the mercury delay line memory. Therefore the time for operations may be decreased by programming the computation so that there is a minimum wait for the next number to be used out of the circulating memory. This kind of programming is called *least wait programming* or *minimum latency coding*. It is often wise to use minimum latency coding for those sections of the instructions which are used the most frequently. Many other good programming techniques, such as shifting instead of multiplying by powers of ten, may also be applied so that the time for the execution of operations may be materially shortened.

No special coding is required to process alphabetic information. The comparison circuits enable the computer to place alphabetic information into proper sequence with the same ease and speed as numerical information.

Input-Output

Uniservos

The regular method for giving information to the computer and taking it from the computer is the use of the magnetic tape memory on the Uniservos. In fact, the Uniservos are so intimately related to the computer that their magnetic tapes may be considered at the same time as part of the memory of the computer and as part of the input-output system for the computer.

This method for providing information for and drawing information from the computer uses blocks of 60 words, i.e., 720 characters for each transfer between Uniservo and computer. As mentioned before, the tape will start from rest, attain maximum speed, read or write one block, and stop in the nonrecorded space existing between blocks, all in 104 milliseconds. The central computer requires only 5½ milliseconds out of the 104, however, to initiate the read or write order by filling either the 60-word input area (register I) or the 60-word output area (register O); the Uniservo completes the operation. This system of "buffer" storage allows the user of Univac to read from one Uniservo reel, write on another, rewind as many as three other reels, and continue computation, all at the same time.

The long-run rate of transfer of information, 7200 characters or 10 blocks per second, is equivalent, for example, to reading or punching all 80 columns of 120 punch cards per second. A full 1500-foot reel of tape thus may hold 1,440,000 characters, being the equivalent of 18,000 punch cards, and may be read or recorded in approximately 3½ minutes.

The basic computer instructions to read from tape are only these:

1*n*0000	Read from Uniservo *n*, one block to input tank I; move tape forward
2*n*0000	Same as above, but move tape backward
300XX0	Write from input tank to 60 consecutive memory locations starting with XX0

A Uniservo can read tape forward or backward with equal facility, but records on tape only in the forward direction. Whenever recording takes place, previous recording on the tape is automatically erased by the same read-write head. Several safety features are provided, however, so that reels of instructions, master file information, etc., cannot be erased.

Card-to-Tape Converter

The Card-to-Tape Converter reads information from 80-column punch cards and records the information on magnetic tape, at a rate of 240 cards per minute. It does this by reading a punch card twice, using two sets of brushes, writing the first result on magnetic tape, and comparing the result on the tape with the second reading of the punch card. If any inequality is determined, the punch card is rejected, the converter stops feeding cards, and the magnetic tape is repositioned to allow recording over the same area.

Other checking features included in the Card-to-Tape Converter are: (1) a mispunch detector, for finding excess punches in a card column; (2) a misfeed detector, which prevents the converter from attempting to feed cards when a card fails to generate the card feed symbol for the next card; (3) a pulse check, to insure that the number of binary ones in a character is odd; (4) a digit count for the comparison; and (5) a "checked card counter" which is stepped by a count of one after all other checks are verified.

The information from any or all of the 80 columns is recorded in a set of 10 words or *blockette* on the tape. The format is controlled by a plugboard which may provide for splitting a card column, rearranging the card information as desired, and filling the blanks in a blockette with zeros or space symbols.

Tape-to-Card Converter

Conversely, the Tape-to-Card Converter reads information on magnetic tape and produces punch cards. The rate of conversion is 120 cards per minute; again, the format is controlled by a plugboard. A digit count is maintained for each blockette; and each character on the magnetic tape is checked to determine that it contains an odd number of binary ones. As each blockette of tape information is read, a card is punched, the card is then read, and then a comparison between the tape information and the card information is performed. If any inequality of information is detected, the card is rejected, and the tape is repositioned to punch another card. A card column that is illegitimately punched will also signal an error and stop the converter.

Unitypers

Unityper I

The Unityper I accepts manual key strokes on the keyboard of a modified electric typewriter and records characters directly on magnetic tape in binary code. It consists of a unit for recording on magnetic tape and an electric typewriter with a standard keyboard and also a ten-key numeric keyboard. If desired, an immediate visual record may be had by attaching a printer.

The Unityper records in blocks of 60 words and provides for a space between blocks. It contains two counters; one counts the characters typed from 1 to 12; the other counts the words typed from 0 to 59. A Unityper also contains at least one optional control using a loop of punched paper tape, and may contain several such controls. An important use for the loop control is the automatic filling of a field with a given character.

With a Unityper, the typist may erase a single character, or a single field, or all the characters back to the beginning of a word, or all the words back to the beginning of a block, depending on the loop controls governing.

Unityper II

A more recent device for recording on magnetic tape is the Unityper II, which is about 1/6 of the size and 1/5 of the cost of Unityper I. The Unityper II consists of a modified Remington Rand electric typewriter, together with a small tape unit mounted at its rear which makes it a self-contained, desk-top, piece of equipment. The keyboard is almost identical with that of the standard typewriter, and so recording on magnetic tape can now be done at approximately the same rate as normal typewriting.

The tape reel used is six inches in diameter, holds 200 feet of tape, and may record more than 55,000 characters. As the tape is recorded, a visible record, 120 characters per line (or blockette), is produced. The typist may erase, and reposition the tape, one character at a time, or else go back to the beginning of the line (blockette).

The typist may select, with the use of the Fill Selector Switch, either zeros or space symbols to fill in the rest of the field, or the blockette (120 characters), or the block (720 characters), in accordance with the setting of the tabulating key on the typewriter.

Verifier

The Verifier is a three-purpose piece of equipment which may be used as a typer, a printer, or a magnetic tape verifier. When used as a Verifier, it provides for checking each character previously recorded on the tape by a different typist with the character key struck by the operator.

In the event of a disagreement the operator attempts to depress the correct key. If she cannot, the error is on the tape and may be corrected; but if the key may be depressed, the disagreement was caused by striking an incorrect key.

Printers

High-Speed Printer

The High-Speed Printer operates at a speed of 600 lines per minute, printing a maximum line of 130 characters. It consists of a tape unit, two electronic cabinets, and the printing unit. Format is controlled by a plugboard, a paper loop, and certain characters recorded on the tape to be printed.

Printed characters are spaced ten to the inch horizontally, and six per inch vertically. Fifty-one kinds of characters are available and include alphabetic capitals, numerals, and 15 punctuation and miscellaneous symbols. The printer will handle any sprocket-fed continuous paper of thickness up to card stock, either blank or preprinted, from 4 inches to 27 inches in width. At least one original copy and four carbon copies can be made.

The printer has checking features which can cause the printer to cease operating in the following cases: an even pulse count; an incorrect digit count; an incorrect character printing; an ended tape; an exhausted paper supply; an exhausted ribbon supply. The paper may be fed at a higher "skipping" speed from one printing area to another; this is controlled by symbols on the tape or punches in a paper tape loop control.

Uniprinter

The low-volume printer used to convert a recorded tape to visible form is the Uniprinter. It consists of a tape unit and a printing unit using a modified Remington Rand electric typewriter. It prints at a rate of about 10 characters per second. Format is controlled almost entirely by the information on the tape. To create an exact visible record of the tape, a function switch may be placed in position to print substitute symbols for nonprinting characters, such as "carriage return," "tabulate," etc. Another switch allows the operator to skip through a section of tape.

Programming

Internal vs. External

The large external memory of Univac makes possible some remarkable feats of programming. Many modern computers use a part, perhaps some 400 registers out of the internal rapid memory of 1000 registers, to store instructions of a fairly general nature. Then the machine computes from these general instructions the specific instruction that applies for each step.

It is possible to instruct the Univac to expand its general program recorded in the internal rapid memory—to "write it out in full," as it were—entering the expanded program into the external memory on magnetic tape. Then Univac in solving a problem can be guided by the expanded specific program on the tape, instead of the condensed general program in the internal memory. Blocks of the expanded program of specific instructions in the external memory are transferred into sections of the internal memory from time to time, to control the machine without calculation of further specific instructions. Consider an example. A Univac was programmed to solve a three-dimensional Poisson partial-differential equation using a 13 by 13 by 13 mesh. One iteration through the mesh took 63 seconds, using the general program as originally written in the internal memory. Then the machine was instructed to calculate the expanded program, and record it in the external memory; the program now occupied 275 blocks, or 16,500 words, which is over 16 times the whole rapid memory. But when the expanded program was used to control the machine to solve this problem, each iteration took 43 seconds, a time saving of just about one-third.

Furthermore, although the internal program was limited to a 13 by 13 by 13 mesh, the instructions generating the internal program were general, for any size mesh. In the external program, the machine needed to look only for "interior boundary points," instead of looking to see if it had proceeded 13 steps, or one plane, etc.

Human vs. Machine Programming

The machine can be used to construct its own program on a much greater scale still. This is accomplished by using a "library of routines" and what are called "compiling routines." The compiling routine assembles, i.e., strings together correctly, routines from the library of routines so as to solve a specific problem.

The library of routines includes series for rapid approximations, iteration formulas for various purposes, tests for judging how many terms to use or how many repetitions to be made, and similar material. In this way, the computer is told only once how to obtain, for example, the sine of x; and ever afterwards it obtains a sine of x by referring to its "education," its library of routines.

The time for the machine to program a problem correctly using machine programming is often less than 1/50 of the time that it takes for a human being to program that problem incorrectly. In fact, for one problem, the time of programming was cut from 2½ days to 1½ minutes.

Some of the Remington Rand compiling routines accept ordinary mathematical symbolism. For example, one problem received from the Army Map Service was the following:

Given: $$\frac{dm}{dq} = \frac{a \cos \phi}{(1 - \epsilon^2 \sin^2 \phi)^{1/2}}$$

$$\frac{d\phi}{dq} = (1 + \epsilon^2 \cos^2 \phi) \cos \phi$$

Desired: $$\frac{d^2m}{dq^2}, \frac{d^3m}{dq^3}, \ldots, \frac{d^{15}m}{dq^{15}}$$

for ϕ equal to certain angles from 0 to 90°.

Using the most recently developed compiling routines, the instruction to Univac to develop the proper program for solving this problem consisted essentially of only the following seven commands (their translation is stated at the side):

Command				Meaning
D*0	00x	000	00u	$u = \sin x$
C00	00x	000	01u	$Du = \cos x$
M*0	00u	0a0	00v	$a_0 u = v$
V*0	00v	p01	00w	$(1 - \epsilon^2 \sin^2 x)^{1/2} = w$
P*0	00w	00v	00y	$y = vw$
U*0	01u	p01	00v	$v = 1 + (Du)^2$
P*0	01u	00v	00w	$w = vDu$

The number of derivatives to be determined and other necessary information may be entered by means of the supervisory control.

This type of automatic programming has been called the *Analytical Differentiator*. Another specifically named type of automatic programming is the *Short Order Code*. It is designed for the solution of mathematical problems that come one of a kind.

The A-2 Compiler is an automatic program which has been in use since 1952 and in which familiarity with the order code of Univac is not required. The programmer lists the operations he wants performed in language that is called *pseudo-code*, in which three letters or digits may specify a routine of hundreds of Univac instructions. The compiler then translates these codes into a finished program. The A-2 Compiler was used on one occasion in the design of a nuclear reactor for a government research center. The men from the center knew nothing of Univac code; yet they were able to prepare the complete program in less than two days. Another use of the

A-2 Compiler was in studies made by a large public utility of the mortality of equipment, which involved complex mathematical analysis. The program was prepared in six minutes. A third example of its use was the study of the characteristics and behavior of gases in a jet stream under about 1900 sets of conditions, made for a large chemical corporation. The program was ready in ten minutes.

Another development of automatic programming is called *Generalized Programming*. It is designed for use by a trained programmer; it uses a special code which is an outgrowth of Univac code, with the addition of extra letters and special terms. Its usefulness is to add master programs to the library. It has been used to process files, sort, merge, and tabulate, to make sales analyses, and to analyze the structures of crystals.

Another type of automatic programming is called *BIOR, Business-Input-Output-Rerun* compiling system. It handles complex aspects of programming input and output procedures, and also those operations necessary for rerunning a program when an error occurs. The user of BIOR writes a few words to specify the type and scope of the input, output, and rerun operations required; the computer compiles the necessary routines, and organizes the program into a finished whole. This type of automatic programming is in use in several Univac installations.

Perhaps the most far-reaching of automatic programs is the one bearing the name *B-Zero Data Processing Compiler*. It is a general-purpose compiling routine that does not require familiarity with the Univac in any way. It permits the programmer to write his orders to the computer in any of several pseudo-codes, pseudo-codes ranging from mathematical notation for scientific problems to plain business English for commercial problems. The programmer does not need any specific knowledge of computer coding but needs only to know how to state his problem and his method of solution in the language he is accustomed to use every day. The automatic program will accept simple statements "tabulate..... by ....." and will produce the Univac program necessary to perform such operations. It will also add input and output operations, rerun procedures, and editing procedures so that the program tape will contain all the necessary information for processing the problem on the Univac.

Thus it is clear that the great bottleneck of human programming for automatic computers is fast on the way to being broken, by giving to the machine the task of programming.

Reliability

Automatic Checking

Approximately 30 per cent of the hardware in Univac is for automatic checking purposes. All the arithmetic units and many control units are duplicated. Every operation is performed by the independent, duplicated units at the same time and the results of each operation are compared for agreement. If there is a discrepancy in the result, the computer stops at once and appropriate neon lamps flash on the supervisory control panel. This enables the operator to locate and determine the reason for the discrepancy.

In addition to duplicated circuits, all information transferred from one point to another in the machine is subjected to an "odd-even check". Because every correct character contains an odd number of binary ones (as a result of the check digit), an even count can only mean an error of some kind. If the count is even, again appropriate neon lamps flash on the supervisory control panel, and the operator can quickly locate the source of error.

In addition to these checks, the entire memory is periodically read through the "odd-even check". As before, if any character gives an even count, the computer stops.

The supervisory control panel gives a continuous picture of the operation of the central computer. Switches and dials allow the operator to examine and test any portion of the memory, registers, or functional circuits. The operator can also print out the information contained in any location and enter, if desired, new information using the supervisory control keyboard. If a failure should occur, a light glows, showing in what component the trouble lies.

Although Univac machines have been in operation since 1950, there is no report from any user that machine errors have actually passed through any central computer. Human errors in programming of course may have been transmitted.

Performance

Several of the first Univacs delivered were contracted for by the National Bureau of Standards, contracting agency for the purchaser. Consequently, before any of these machines was accepted by the Bureau of Standards, rigorous governmental acceptance tests had to be passed.

In early 1955 some figures were gathered on the performance of

Univac central computers at six installations over periods of six to ten weeks. The installations were: General Electric Company, Louisville, Ky.; Air Materiel Command; Metropolitan Life Insurance Company, New York, N.Y.; Army Map Service; Remington Rand Service Bureau, New York, N.Y.; and U.S. Steel Corporation, Pittsburgh, Pa. The total scheduled operating hours were 5191.43; the actual operating hours were 4818.67; and the performance percentage was 92.9 per cent. The performance percentage ranged from 84.0 to 97.8.

Construction

All causes of trouble are systematically investigated. Remington Rand engineers have continually improved circuit design; since 1951 some 5700 distinct engineering changes have been made in the computer and its tape units. An example of the effectiveness of the process of improving circuits is the following: At the end of 4000 hours of operation on Univac No. 1, about 8 per cent of the electronic tubes of type 25L6 had had to be replaced; on Univac No. 3, only about 2 per cent of these tubes had had to be replaced.

The machine is carefully fused, with fuses of the pop-up type. The machine contains 116 different DC voltages, and there is a voltage monitoring equipment which "watches" these voltages and tests them successively.

All parts of the system are readily accessible for maintenance. Separate circuits can be isolated and placed on what are called "extenders" so that maintenance men may have easy access to all parts of the circuits.

Under normal conditions, Univac tape can be passed over a magnetic head for reading and recording several thousand times without appreciable effect on the magnetic plated material. It is not harmed by heat; at a temperature where plastic tape is destroyed (500°F), Univac tape is unaffected. Since ordinary punch cards wear out in 700 to 1000 passes through punch card machines, it is clear that Univac tape wears several times as long.

Univac II

Univac II is the successor to Univac I and is to be ready by the end of 1957. It is the result of unremitting research by three divisions of Remington Rand: the Eckert-Mauchly Division in Philadelphia; the Engineering Research Associates Division in St. Paul, Minnesota; and the Institute for Advanced Research in Norwalk, Connecticut. In addition to all of the reliability developed in Univac I, Univac II will contain some new features.

A magnetic core memory will be used in place of the mercury delay line memory. The new memory will have a capacity of 24,000 characters and may be supplemented to provide a total of 120,000 characters.

The main advantages of the new magnetic core memory will be increased speed, greater compactness, tolerance of wide heat fluctuations, lower cost, and permanence of stored information if the power is interrupted.

The external memory and input-output medium for Univac II will continue to be magnetic tape, but improved design of the Uniservos and greater writing density for the magnetic tape will increase tape capacity and overall speed by a factor of two. The tape will start, read or write a block (720 characters), and stop in 50 milliseconds instead of 104. The rate for reading and writing will be 20,000 characters per second; and a 1500-foot reel of tape will hold 2,900,000 characters.

. The number of Uniservos which may be employed is increased from ten to sixteen. Additional instructions will be provided. Internal operating speeds will be approximately doubled.

VI:2 IBM TYPES 701, 702, 705, AND 704

A family of large, high-speed, automatic digital computers consists of International Business Machines' Types 701, 702, 705, and 704. The earliest of these three machines is Type 701; it has been in use since 1953 in a number of installations. The first Type 702 went into use in 1954; the Type 705 is scheduled to go into use early in 1956; the 704 later in 1956. The 702, 705, and 704 consist basically of the same equipment as the 701, but with improvements, some of them of much significance. We shall describe the 701 in detail, and mention the main changes for the 702, 705, and 704.

The purpose of the IBM Type 701 is large-scale scientific and technical computing; but it has also been used to considerable advantage in some commercial and accounting applications. Types

702 and 705 are even more adapted to business purposes. Type 704 is an improved version of Type 701 for scientific and technical computing mainly, but with higher speed and increased flexibility.

The Machine as a Whole

In Figure 49 the general layout of the Type 701 system is shown. The space required is about 2500 square feet. The power consumed is about 88 kilowatts for the Type 701, 63 kilowatts for the Type 705, and 72 kilowatts for the Type 704.

The Type 701 system is transportable in 12 boxes. The heaviest unit is the printer, a modified IBM Type 407. The computer is a

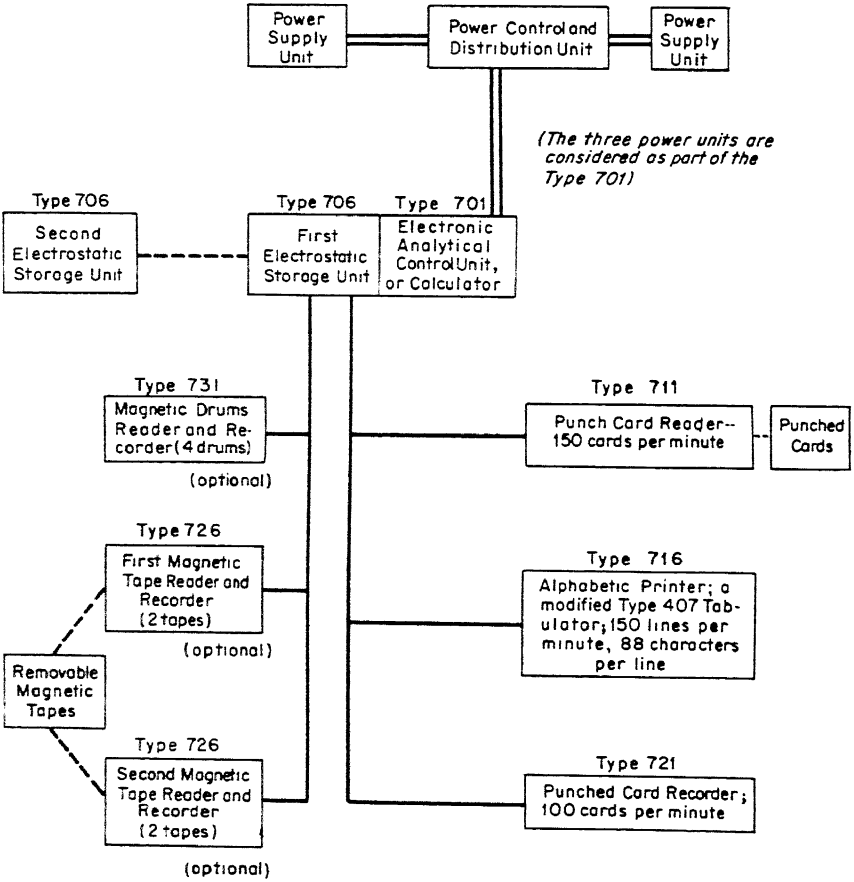

Power Supply Unit
Power Control and Distribution Unit
Power Supply Unit
(The three power units are considered as part of the Type 701)
Type 706
Second Electrostatic Storage Unit
Type 706
First Electrostatic Storage Unit
Type 701
Electronic Analytical Control Unit, or Calculator
Type 731
Magnetic Drums Reader and Recorder (4 drums)
(optional)
Type 711
Punch Card Reader-- 150 cards per minute
Punched Cards
Type 726
First Magnetic Tape Reader and Recorder (2 tapes)
(optional)
Type 716
Alphabetic Printer; a modified Type 407 Tabulator; 150 lines per minute, 88 characters per line
Removable Magnetic Tapes
Type 726
Second Magnetic Tape Reader and Recorder (2 tapes)
(optional)
Type 721
Punched Card Recorder; 100 cards per minute

Figure 49. General layout of an IBM Type 701 System.

parallel, binary machine, handling words of 36 binary digits, one of them being the algebraic sign; and it operates internally in the binary system of notation, as does the Type 704. The 702 and 705 operate internally in the decimal system of notation, and alphabetic, numerical, and symbolic characters are provided.

Memory

The IBM Type 701 has three kinds of memory: electrostatic storage, magnetic drum, and magnetic tape. The Type 704 also has magnetic drum and magnetic tape memory, but its internal high-speed memory is magnetic core storage.

Electrostatic Storage

The electrostatic storage memory is the rapid memory of the Type 701. One unit (Type 706) consists of 72 cathode-ray tubes storing 1024 binary digits per tube, providing 2048 registers of 36 binary digits. An installation may include a second unit, thus obtaining 4096 registers of rapid memory. Accordingly, the total rapid memory is over 140,000 binary digits. All information to other parts of the machine passes through the electrostatic storage memory, which thus acts like a union railroad terminal.

Magnetic Core Storage

The internal high-speed memory of the Type 704 is magnetic core storage. The cores can retain information indefinitely, and recall it in a few millionths of a second. A group of 36 cores constitutes one register; and there are 4096 such registers in a machine unit. Either one or two such units may be provided in an installation.

Magnetic Drum

The magnetic drum memory is the intermediate memory of these machines. In the Type 701, the magnetic drum memory consists physically of two units, each called a Type 731 and each of these units physically contains one magnetic drum, which, however, is logically organized as two magnetic drums. On each magnetic drum information is recorded in parallel on 36 tracks around the drum; 2048 binary digits of information are stored in each track, with approximately 50 binary digits per inch, and 40 inches of circumference to the drum. The total amount of memory in the four drums, therefore, is about 300,000 binary digits. The read-in and read-out speed for the magnetic drums is 800 words per second, or about 28,000 binary digits per second, and the average access time for the magnetic drum is 30 milliseconds.

The Type 704 has four magnetic drum units, logically organized as eight magnetic drums, double the number possessed by the Type 701. Thus the 704 has a total storage capacity of about 600,000 binary digits to the 701's 300,000. The read-in and read-out speed is 10,000 words per second, and the average access time is 12 milliseconds.

Magnetic Tape

The third part of the memory of the IBM Type 701 system consists of up to four magnetic tape units, identified as Type 726. Each of these units will at any one time utilize one 1400-foot reel of magnetic tape. Tape passes under the magnetic heads at the rate of 75 inches per second after it gains full speed, which requires 10 milliseconds. The machine uses 1/2-inch-wide plastic tape coated with magnetic iron oxide. The tape which is currently being supplied is completely free of imperfections; in fact 200 miles of perfect tape had been supplied up to May 1955. The density of information on the tape is 100 binary digits per inch per channel, in each of 7 channels; but one channel holds a binary digit for synchronization and for an odd-even check, leaving six for holding useful information.

Between one block of information on the tape and the next block, a space of one inch is allowed; but the blocks may be as long or as short as desired; in other words, a block may be 50 words long or 500 words long or some other number. An "end of record" signal at the end of a block of words gives the machine an indication that a block has been read.

These figures combine to give the following characteristics for the Type 701: about 45,000 binary digits per second of input or output; about 10 million binary digits stored per reel; and about 40 million binary digits accessible at one time to the machine.

In the Type 705, the amount of magnetic tape on a reel is 2400 feet; the information density is 200 characters per inch, with a 3/4-inch inter-record gap. Thus a reel of tape is equivalent to

25,000 punch cards of 80 columns each, or 5 million characters. The maximum number of tape units is 100. The tape moves at 75 inches per second, or 15,000 characters per second. The read-write speed is 10 milliseconds for each record plus 67 microseconds for each character. Simultaneous reading of input tape and writing on output tape may be arranged by programming.

The Type 704 uses ten tapes as compared with the 701's four; the length of the reel is 2400 feet, as with the 705. About 32,400,000 binary digits can be stored on each tape of the Type 704. The rate of transmission of information on the Type 704 is twice that of the 701, or 2500 words per second.

Arithmetic Unit

The Type 701 uses one-address orders. The time for a one-address addition is from 36 to 60 microseconds, depending upon the regeneration requirements of the electrostatic storage memory. This is the time needed to get the addend out of a register, and add it to the augend already in the accumulator. The time for a transfer is similarly from 24 to 48 microseconds. The minimum times may be obtained by certain kinds of efficient programming, which will now be explained. Of the 33 possible orders, 31 are short like addition and transfer, and take not more than 48 or 60 microseconds to perform. Two are long; these are multiplication and division, and take 456 microseconds to perform. But right after a long order (multiplication or division), the next 12 orders (excluding multiplication, division, and input-output operation) ordinarily take the minimum time, because the regeneration of the electrostatic memory has taken place during the long orders. Accordingly, the economical way of scheduling orders is one multiplication or division followed by 10 or 11 short orders.

In economical programming of this kind, the machine can perform about 14,000 single-address operations per second. If there are no multiplications, the machine can perform about 16,000 single-address instructions per second. If the machine were to perform only multiplications, its speed would be a little over 2000 single-address multiplications per second.

In the Type 705 addition time for two 10 decimal digit numbers is 204 microseconds, and multiplication time for two 5 decimal digit numbers is 800 microseconds.

The Type 704 can perform 41,700 single-address operations per second, as compared to the 14,000 operations of which the Type 701 is capable.

MQ Register

In the arithmetic unit of the Type 701 is a register called the MQ register, which holds the multiplier in a multiplication, the quotient in a division, and other information at other times. To transfer a number from input into the arithmetic unit or from the arithmetic unit into output also requires the use of the MQ register.

In the case of input to the computer, the process for reading one word of 36 binary digits from the magnetic tape into the electrostatic storage is from tape to MQ register and from MQ register to electrostatic storage register. The time required is 540 microseconds. During this time the MQ register is unavailable for other purposes.

In the case of output from the computer, the process of printing a line of 120 characters using the Type 716 alphabetic printer connected to the machine requires 400 milliseconds. During 230 milliseconds of this time, the MQ register must at certain specified intervals execute 24 copying instructions. In other words, during these 230,000 microseconds, the arithmetic unit is only free to perform multiplications or divisions (each taking 456 microseconds) provided they fall entirely within one of the 23 intervals between the copying instructions. So, either the programmer must meet this requirement in his programming, or else he must schedule output—which is relatively slow—outside of the main computing program for the problem. The second choice is usually preferable.

In Types 702, 705, and 704, a section of the rapid memory is independently connected to input or output, so that computing is not held up during reading and writing on tapes.

Input-Output

All the machines will accept as input both recorded magnetic tape and IBM punch cards. For output, the machines will produce recorded magnetic tape, punched IBM cards, and printed information. In the case of the Type 701, the printer is a modified IBM Type 407 tabulator, and prints 2½ lines of 120 characters a line per second, or 300 characters per second.

Programming

Each order consists of a sign, five binary digits for operation and decoding, and twelve binary digits for addresses. Any one of 33 orders may be given to the machine.

The IBM Corporation has published a comprehensive set of programs for the Type 701. Typical programs include decimal-to-binary conversion and vice versa, printing, punching, and other programs. The medium of publication is punch cards, recording 24 full words of 36 binary digits on each card; i.e., 864 binary digits on an 80-column card with 12 positions for punches.

In programming, the Type 704 shows considerable advances over the Type 701: it has increased logical flexibility for solving complex problems; it has three index registers for automatic counting and modification of addresses; it has more testing instructions; it has a complete set of instructions which will perform floating-point arithmetic; etc.

The type of programming system recommended for the Type 704 is called *symbolic programming*. In order for an automatic digital computer to execute a program, all machine words in the program need to be assigned definite locations in storage, and all quantities in the program need to be assigned definite numerical values. This is called an *absolute program*. However, the best assignment of storage space cannot be made until after the program is written out and the demands for such space are known. Symbolic programming makes it possible to postpone the definite assignment of storage space until the demands are known. In such programming, the program is written first in terms of symbols denoting the storage locations (as yet unknown) of all the words to which the program must refer. After this has been done, the program is fitted into storage by giving the symbols for storage locations definite numerical values and converting it into an absolute program. The symbolic program is given to the machine in the form of standard cards, punched from the programming record, and standard cards which specify storage allocation. The machine then produces the absolute program.

Reliability

The Type 701 has facilities for automatic checking in the printer, and in the magnetic tapes. All other checking may be programmed at the coder's option. For example, there is an automatic odd-even check in the information on the magnetic tapes: it is the function of the seventh binary digit to report whether the other six binary digits are composed of an even number or an odd number of binary ones. There is no automatic checking in the arithmetic unit. The Type 704 has a more elaborate checking system associated with the tape operations than the Type 701.

Over 18 installations of the Type 701 have been made. On the average, successful performance has been about 90 per cent of scheduled running time.

VI:3 ERA TYPE 1103

Another of the important high-speed, automatic digital computers of great capacity is the machine known as the ERA Type 1103 or Univac-Scientific computer. Two recent improved variations are known as the 1103 A and the 1103 B. This machine is produced by Engineering Research Associates Division, Remington Rand, Inc., St. Paul, Minnesota. It has recently been made compatible with the commercial Univac so that both can work together.

The purpose of this machine is to solve mathematical, scientific, and engineering problems, including problems requiring the reduction of data in real time.

Machine as a Whole

The Type 1103 computer or Univac-Scientific computer consists of the central computer and a number of necessary or optional auxiliary units as follows:

—devices for handling magnetic tape;

—a converter of magnetic tape to punch cards;

—a converter of punch cards to magnetic tape;

—Unityper II (see Section VI:1 on Univac);

—a High Speed Printer (see Section VI:1 on Univac);

—a photoelectric paper-tape reader;

–a directly connected electric typewriter;
–a high-speed paper-tape punch;
–a punch-card reader;
–a card punch;
–Teletype communication circuits;
–graphic visual displays;
–analog-to-digital converters for converting instrument readings into computer data;
–signal circuits for operating mechanisms that actuate processes.

The space required for the machine is approximately 60 feet by 20 feet.

A machine word consists of 36 binary digits, with the binary point at the extreme right; consequently, fractions have to be scaled. A negative number is distinguished by having 1 in the column at the extreme left; a positive number, by having 0 in this column.

Memory

Rapid Memory

The rapid memory of the Type 1103 consists of 1024 or 4096 registers. Originally, this rapid memory consisted of 1024 registers of electrostatic storage in cathode-ray tubes; several such machines are in operation. Whenever the machine is not reading from or writing into the electrostatic memory, regeneration goes on, with a cycle of 8 microseconds. The access time is about 10 microseconds.

Currently, the rapid memory of the Type 1103 consists of 4096 registers of magnetic core storage. The first of these new memories was delivered in 1954, and has been found to be remarkably reliable and trouble-free. The reading and writing is carried out in parallel, and the access time to any word is about 10 microseconds.

Intermediate Memory – Magnetic Drum

The intermediate memory of the machine consists of 16,384 registers of magnetic drum storage. This memory is addressed, permitting individual registers on the drum to be called for and consulted individually. The single drum is about 17 inches in diameter and rotates at about 30 revolutions per second; the peripheral velocity is held constant. The resulting surface speed is about 1600 inches per second; the pulse density is about 80 polarized spots per inch of circumference. There are 4096 bits in one channel around the drum.

There are four groups of magnetic heads, with 36 heads in each group and located radially around the drum. Each is individually adjustable.

A system referred to as *interlacing* of the addresses of registers around the drum has been devised. Under this system consecutive addresses are not placed consecutively on the drum, but at staggered intervals chosen so that time waiting for the address to be read by the magnetic heads is minimized.

The speed of transfer of information from the high-speed memory to the intermediate memory, and vice versa, is 30,000 binary words per second.

Slow Memory – Magnetic Tape

In addition to the first two memories, both the 1103 and the 1103 A have magnetic tape memory. For the 1103, this memory consists of four magnetic tape handling units made by Raytheon Manufacturing Co. or Potter Instrument Co. For the 1103 A, the tape handling units are Uniservos (see the section on Univac); from one to ten Uniservos may be employed with the 1103 A, but for the average installation, four to six units would be appropriate.

Reading, writing, and moving the tape forwards or backwards are governed by programmed controls. For the 1103, blocks of 32 words are the units in which these operations are carried out; for the 1103 A, information is handled in blocks of 120 computer words, or in "blockettes" of 20 computer words. The free-running rate of transfer of information between computer and tapes is about 1810 computer words per second. A great advantage of the 1103 A design is that it makes possible the use of standard Univac peripheral equipment, though of course not on a real-time basis of operation.

Input-Output

The basic set of input-output equipment is: (1) a photoelectric punched paper tape reader made by ERA or a photoelectric reader made by Ferranti; (2) a high-speed teletype paper-tape punch made by the Teletype Corporation, Chicago, which punches at the rate of 60 characters a second; (3) a Remington Rand electric typewriter for monitoring the computer; (4) magnetic tape as mentioned above under slow memory.

Optional input-output equipment consists of: (1) a card reader that reads 90-column Remington Rand punch cards; (2) a card reader that reads 80-column punch cards, which is a machine manufactured by Bull S. A., a French company, and imported by Remington Rand; (3) an oscilloscope to display results.

The computer has in addition two special input-output registers: (1) Terminal Register A consisting of flip-flops that store a total of 8 bits; and (2) Terminal Register B consisting of flip-flops that store a total of 36 bits. These two registers are under the control of: (1) the computer; (2) any auxiliary equipment that takes in data from a real-time process; or (3) any auxiliary equipment that puts out data to an actuator or controller of a real-time process. Terminal Register B can be loaded with information from real-time input at the rate of 36 binary digits every 24 microseconds and it can then transfer that information into the rapid memory in not more than 10 microseconds.

Auxiliary equipment for data-acceptance and data-presentation in real-time may be obtained.

Arithmetic Unit

The orders the machine uses are two-address orders. When only the rapid memory is involved, the time for a two-address addition is 64 microseconds or less. A two-address multiplication requires 114 microseconds up to 420 microseconds, giving an average of about 266 microseconds. The accumulator in the arithmetic unit will hold double precision numbers of 72 binary digits. The model 1103 A and the 1103 B are identical except that the 1103 B possesses four additional instructions to accomplish "floating point" arithmetic operation.

Programming

There are over 40 types of orders in the instruction code. Each order word contains a six-bit code which specifies an operation and two more 15-bit codes which ordinarily are the addresses of two registers. Since there are 63 possible combinations of six binary digits (omitting the combination 000000), there is room for expansion of the order code.

The set of over 40 orders has been carefully designed, based on many suggestions and much experience by the groups that have been operating predecessors of the current model 1103 since 1950. One of the orders is a "repeat" order, which causes the next order to be carried out a specified number of times. Other orders also are powerful and lead to increased speed in problems like matrix multiplications.

The program for a problem may be stored in the magnetic drum memory as well as in the rapid memory. The individual addressing of magnetic drum registers makes it possible to execute the program directly from addresses of registers on the drum, without first transferring drum information to the high-speed memory; and with skill in programming, direct programming in this way can be accomplished in many cases without losing very much computing time.

Reliability

Construction

From the beginning of design and construction of the computer, concentrated attention has been given to reliability. All ERA equipment is built to JAN (Joint Army Navy) specifications. The machine operates at 500 kilocycles, a repetition rate that is slower by a factor of 2 or 3 than that of many other machines. The machine is synchronized by a time track on the magnetic drum; its pulses are spaced at 125 kilocycles and they are electronically multiplied by 4. There is just one magnetic drum; it constitutes the master clock for the machine. No soldering is needed for reconnecting the machine in an installation; all connections are screw terminals.

The ordinary level of the voltage for the heaters for most of the electronic tubes in the machine is 6.3 volts. But each chassis is so designed that when the tubes are new, it will operate perfectly at a level of 4.7 volts for the heaters. This is part of the system of marginal checking built into the machine, so that diagnosis of likely tube failures can be carried out ahead of time.

In general, no automatic checking is built into the machine. One exception is that in writing words on magnetic tape, each word is written twice so that it may be completely verified. Also, the machine has an automatic check on the main translator of orders. Since not all of the 64 possible order codes are possible orders, there are a number of impossible orders, and if one of these is delivered to the main translator as an order, the machine reports an error. Otherwise the machine relies on programmed checking for accuracy in the solution of problems. Before any problem is put in the machine, a programmed check based on a similar problem with known answer can be put in to test whether the machine is in perfect operation. Naturally, this does not prove that the computer is in perfect operation, but it makes the probability very high.

Marginal checking during preventive maintenance is also employed. In addition to the test of reduced voltage on the heaters of tubes, the pulse rate is raised from 500 KC to 750 KC to test the machine.

Applications

The ERA 1103 or Univac-Scientific computer is particularly useful for the control of industrial processes and scientific experimentation that take place at very high speeds. For example, at the White Sands Proving Ground the current task of the machine is to compute and analyze the data obtained from scores of instruments which track each guided missile in flight. The sooner this is done, the faster the determination of the cause of deviations from the expected trajectory. Ordinarily, the computations would require 250 to 500 hours; with the Univac-Scientific computer the time for computation is reduced to 5 to 10 minutes, and up to ten missile firings a day can be handled. Other installations where this machine is in use are at Convair, Eglin Air Force Base, Ramo-Wooldridge Corporation, and the Operations Research Office at Johns Hopkins University. Flight simulation and actual flight control are among the problems planned for this computer.

SECTION VII

APPLICATIONS OF AUTOMATIC COMPUTING MACHINES

VII:1 WHOSE WORK CAN AUTOMATIC COMPUTERS DO?

We turn now to the applications of automatic computers. This is a large subject, of course, and it will be many years before the last word has been said. But a good way to begin the discussion of this subject is to ask three questions:

1–What kinds of persons earn their living chiefly or partly by mental work?

2–How numerous are they?

3–To what extent can their mental work be done by machine?

Now a computing machine has an application when it can do work. And this work either replaces work now being done by some person in the course of his regular occupation, or else it is work which conceivably some person if he were clever enough, fast enough, and low-paid enough, would be hired to do. This second aspect is very important, for it is easy to observe that no person in the world can do 10,000 calculating operations in a second. In fact, until automatic computers came into existence, the practical alternative in many situations was to let desired work go undone—even if the thought of possibly doing such work crossed one's mind—in view of the impossibility of actually doing it.

The Occupations of People

We can approach the answers to these questions by studying an important table compiled by the U. S. Bureau of the Census, that shows the occupations of people. This table is published as "Table 224.–Detailed Occupation of the Experienced Civilian Labor Force and of Employed Persons, by Sex: 1950" in the "Statistical Abstract of the United States, 1953," issued by the U.S. Government Printing Office, pages 198-206.

The first extract that we shall make from Table 224 comprises Table 22 given here. This extract shows the "experienced civilian labor force" of the United States in 1950, consisting of some 59 million persons who were 14 years old and over, subdivided into twelve main occupational classifications.

TABLE 22

EXPERIENCED CIVILIAN LABOR FORCE, 1950, BY MAIN OCCUPATIONAL GROUP*

Main Occupational Group	Number of Persons in thousands
Total, 14 years old and over	58,999
Professional, technical, and kindred workers	4,988
Farmers and farm managers	4,321
Managers, officials, and proprietors, excluding farm	5,076
Clerical and kindred workers	7,070
Sales workers	4,044
Craftsmen, foremen, and kindred workers	8,153
Operatives and kindred workers	11,716
Private household workers	1,488
Service workers, except private household	4,512
Farm laborers and foremen	2,515
Laborers, except farm and mine	3,751
Occupation not reported	1,366

*Taken from "Table 224.—Detailed Occupation of the Experienced Civilian Labor Force and of Employed Persons, by Sex: 1950," in the "Statistical Abstract of the United States, 1953," pp. 198-206. (Figures separately rounded)

We read down the list of these twelve main classifications, remembering that none of the automatic computers so far in existence can yet recognize things, or understand words. And we realize that actual replacement by computers of persons having direct contact with things (like growing crops on a farm) or direct contact with people (like a salesman of automobiles) is as yet close to impossible, although radar "sees" and a vending machine "sells".

The first advantage of examining this table now appears: we start placing the work that can be done by present-day automatic computing machinery into its proper perspective, among all the different kinds of work performed in the country. For example, referring to Table 224 we find that a main occupational group "craftsmen, foremen, and kindred workers" includes the following: bakers, blacksmiths, boilermakers, bookbinders, brickmasons, stonemasons and tile setters, cabinetmakers, carpenters, cement and concrete finishers, compositors and typesetters, cranemen, derrickmen and hoistmen, decorators and window dressers, foremen (subdivided by industry), ... mechanics and repairmen, ... plumbers and pipe fitters, ...

Such occupations provide slim pickings for someone who thinks of replacing labor by automatic computing machinery alone, although the possibility of still more advanced physical machinery than now exists, coupled with some "reasoning" or "computing" circuits, is important and must not be overlooked. This is a subject now receiving intensive study under the name "automation."But it is easy to see from reading the table that most work done in the country is still not work done with thoughts and the symbols for them, but work done with things and with people.

In this list appear two groups among which we can find numbers of people who can be either replaced or assisted by automatic computers. These two groups are:

Professional, technical, and kindred workers
Clerical and kindred workers

Professional Workers

From Table 224, we can make a second extract, showing the occupational subdivisions of the group "professional, technical, and kindred workers." This extract appears in Table 23. The occupational subdivision is shown in column (1) and the number of thousands of persons in column (2). In column (3) is shown an "estimated percent of persons replaceable by automatic computing machinery over the next five or ten years." In column (4) a result, estimated number of workers replaceable by automatic computing machinery, is shown, equal to the product of the number in column (2) and the per cent in column (3).

The "estimated percent of persons replaceable by automatic computing machinery" shown in column (3) requires explanation. Insufficient information exists to determine this figure any closer than a very rough estimate. However, the more mathematical and computational that a certain profession is, the more likely it is that the introduction of automatic computing machinery will tend to replace a portion of the persons employed in that profession. This portion has been estimated in column (3). As more information becomes available, this portion or per cent can be estimated in a more reasonable way, and the figures recomputed.

In any statistical situation like this, many separate estimates of a magnitude, as shown in column (3), are to be preferred to a single lumped estimate, applying to the total of the whole column.

TABLE 23

PROFESSIONAL, TECHNICAL AND KINDRED WORKERS BY OCCUPATIONAL SUBDIVISION†

(1) Occupational Group	(2) Number in Thousands	(3) Per cent	(4) Replaceable Professional Workers = (2) × (3)
Total professional, technical, and kindred workers	4,988	1.9	94.5
Accountants and auditors	383	10	38.3
Architects	25	5	1.3
Chemists	76	2	1.5
Designers	40	5	2.0
Draftsmen	125	10	12.5
Engineers, aeronautical	18	5	.9
” , chemical	33	5	1.7
” , civil	126	2	2.5
” , electrical	108	5	5.4
” , industrial	41	2	.8
” , mechanical	113	5	5.7
” , metallurgical, and metallurgists	11	2	.2
” , mining	11	0	0
” , nec*	74	2	1.5
Natural scientists (nec)	41	2	.8
Professional, technical, and kindred workers (nec)	117	1	1.2
Professional, technical, and kindred workers classified individually in the original table but not reported individually in this extract	3,646	0.5	18.2

*nec = not elsewhere classified.

†Taken from "Table 224.—Detailed Occupation of the Experienced Civilian Labor Force and of Employed Persons, by Sex: 1950," in the "Statistical Abstract of the United States: 1953," pp. 198-206.

This computation shows as a final result rounded off that about 2 per cent of professional, technical, and kindred workers, or about 100,000 persons out of five million, may be replaced by automatic computers over the next five to ten years.

But what about equivalent human labor power provided by automatic computers that do not replace persons but simply make an addition to the productive power of the country?

Suppose we estimate roughly that five times as much labor power will be added as will be replaced. To draw a comparison, in the days of the horse and buggy, average miles per day traveled by a worker probably was around 3 or 4. Nowadays with motor cars, subways, commuting trains, etc., the average miles per day traveled by a worker must be over 40 miles.

Thus the development of automatic computers, so far as the professional, technical, and kindred field is concerned, may over the next five or ten years add the equivalent of 600,000 persons to the labor force. If the average annual income of one of these persons is $6000, then the addition to the working power of the country will be around 3 or 4 billion dollars a year.

Clerical Workers

From Table 224, we can make a third extract, showing the occupational subdivisions of the group "clerical and kindred workers." This extract appears in Table 24.

As before, the occupational subdivision is shown in column (1) and the number of thousands of persons is shown in column (2). An "estimated per cent of clerks replaceable by automatic computing machinery over the next five or ten years" is shown in column (3). The result of multiplying the number of persons and the per cent is shown in column (4): the "estimated number of clerks replaceable by automatic computing machinery." The per cents of course again are rough estimates, but at least the per cent zero is applied to those groups where the duties of the occupation require much recognition of things and many contacts with people.

This computation shows as a rounded off final result about one million out of seven million "clerks and kindred workers" estimated to be replaced by automatic computing equipment over the next five to ten years. The figure seems high; but here again, as soon as more reliable per cents are available, they can be inserted in the table and a better estimate may be made.

TABLE 24

CLERICAL AND KINDRED WORKERS BY OCCUPATIONAL SUBDIVISION*

(1) Occupational Subdivision	(2) Number in Thousands	(3) Per cent	(4) Replaceable Clerks = (2)×(3)
Total clerical and kindred workers	7,070	16.0	1129
Agents	126	0	
Attendants and assistants, library	13	0	
Attendants, physician's and dentist's offices	42	0	
Baggagemen, transportation	8	0	
Bank tellers	64	0	
Bookkeepers	736	40	294
Cashiers	234	20	47
Collectors, bill and account	24	0	
Dispatchers, and starters, vehicle	32	0	
Express messengers, and railway mail clerks	19	0	
Mail carriers	168	10	17
Messengers and office boys	59	0	
Office machine operators	146	0	
Shipping and receiving clerks	297	0	
Stenographers, typists and secretaries	1622	20	324
Telegraph messengers	8	0	
Telegraph operators	35	0	
Telephone operators	366	40	146
Ticket, station, and express agents	60	0	
Clerical and kindred workers, not elsewhere classified	3011	10	301

*Taken from "Table 224.—Detailed Occupation of Experienced Civilian Labor Force and of Employed Persons, by Sex: 1950," p. 200, in the "Statistical Abstract of the United States: 1953."

Suppose we proceed now to estimate the equivalent human labor power added to the country's working power provided by the assistance of automatic computing machinery in clerical and kindred work. It is worth noting that already a huge amount of clerical work is being performed by punch card machinery, as in the Federal Social Security account keeping. This is reflected in the census report of 146,000 office machine operators (see Table 24). Considering the strides already taken, suppose we estimate again that five times as much clerical labor power will be added as will be replaced.

Thus the development of automatic computing machinery, so far as the clerical and kindred field is concerned, may over the next five or ten years add the equivalent of six million persons to the labor force. If the average annual income of each of these clerical persons is about $2500, then the addition to the working power of the country will be on the order of 15 billion dollars a year.

Considering both the professional group and the clerical group, we can guess, as a rough estimate, that on the order of 10 to 20 billion dollars of work done a year will be the effect of the application of automatic computing machinery.

VII:2 WHAT PEOPLE MAY BUY AUTOMATIC COMPUTERS?

Now it is all very well to consider that after the next few years automatic computing machinery may be able to bring forth in each year a prodigious potential value of work done. But before any automatic computer actually starts working, it has to be bought from the manufacturer by a particular organization, and put to use in some specific place in business, industry, government, or other economic activity. (Of course, manufacturer and user will occasionally be one and the same organization.) Such organizations constitute the effective market, the people who will buy automatic computers.

Conceivable Customers

Who are conceivable customers? A conceivable customer is an organization which can afford to pay the minimum prevailing price for an automatic computer and which has a considerable amount of computing to be done. The minimum prevailing price is around $50,000 for purchase or $12,000 a year for rental.

Certain factors exist which show clearly the possibility of use of an automatic computer in any given organization.

Number of Persons Doing Computing

The first factor is the number of persons employed in the organition who actually do some computing. Of course, the definition of computing may vary to some degree according to the type of computer which may be under consideration. A simple analog computer is particularly useful for solving differential equations; in this case only persons doing that work would be included as persons computing. A big general purpose automatic digital computer may be useful in filing, and bringing records up to date; in this case persons doing computing would be a much larger group.

If less than four persons do computing in an organization, the chance of an automatic digital computer being useful to that organization is remote. If the average salary is $3000 a year, this implies a present annual expense of $12,000 a year for computing. But not all of this can be saved by any automatic computer; perhaps half can be saved, or $6000 a year. This sum annually, or alternatively, a single sum of $24,000, assuming a four-year amortization, would very likely not pay for an adequate automatic computer.

Number and Kinds of Nonautomatic Computers in Use

A second important factor which indicates whether an automatic computer might be sold to an organization is the number and kinds of nonautomatic computers in use in that organization.

Adding machines of course do not indicate much since their replacement will often depend on a good method of computer input as a byproduct of other operations – and this is a wide field for future development rather than an important field for present application.

Desk calculating machines that will multiply or divide, and punch card machines, especially electronic calculating punches, are good indications. If an organization has many of these machines, it is clearly an excellent prospect for an automatic computer, which will string together the operations being done on this equipment, and perform them automatically.

As a rule of thumb, if less than four desk calculators are in use in an organization, it is hardly a good prospect.

Amount and Kinds of Computing Work

The third factor is the quantity of computing work of various types done in the organization. Computing may be divided basically into two kinds: (1) clerical, including sorting, filing, listing, totaling, looking up data in tables or files, entering data on records, etc., as performed by clerks in many kinds of businesses; and (2) engineering, including mathematical, scientific, and technical calculations, research operations, etc., as performed by human computers, scientists, engineers, and statisticians, in many kinds of laboratories, research institutes, etc. The first kind may be called *clerical computing*. The second kind may be called *engineering computing*. The amount of clerical computing is undoubtedly over 50 times the amount of engineering computing, although engineering computing has received much the lion's share of publicity in recent years, since it has been the area of application of spectacular new electronic computers of vast power, such as Eniac in 1946, and the IBM 701 in 1953.

Size of the Organization

A fourth factor affecting the possibility of use of an automatic computer is the size of the organization. One useful indicator of size is the number of employees; this figure enables many estimates to be made. A second indicator of size is the financial resources which the management of the organization is willing to invest in information-handling equipment for the purposes of its business. Before an organization could venture to purchase an automatic computer for $50,000, it probably would have to have at least relatively uncommitted financial resources of several times that amount.

Clerical computing has been for many years an area of application for a large amount of mechanization, by means of punch card machines. An automatic computer capable of doing clerical computing efficiently has of course a much larger market than one which is limited to engineering computing.

Degree of Centralization

Another factor affecting the possibility of use of an automatic computer is the degree to which the company is centralized or decentralized. It is difficult to use a single computer from several geographic locations. If a company is considerably decentralized, it may be compelled to use smaller and less automatic computing machinery.

The Possible Market

The factors listed above that determine the class of conceivable customers, the possible market, are not directly reported in most of the statistics of census type which appear to be available. Thus, we have to determine the possible market indirectly using what statistics can be found. It is, however, possible to obtain from existing statistical sources the number of organizations in the United States classified by industry and by number of employees. It is also possible to obtain a reasonable estimate of the proportion of total employees who are engineers and the proportion of total employees who are clerical, all classified by industry. Therefore, the following criteria are available or computable: total number of employees, number of engineers, and number of clerical employees, subdivided by industry and by total number of employees in the establishment. From this information about the possible market we have a hope of roughly estimating the effective market.

Establishments Classified by Industry and by Size

The first source of information for us is a certain report published by the Office of Domestic Commerce and compiled by the Bureau of Old Age and Survivors Insurance of the Social Security Administration. This report is called "Business Establishments, Employment, and Taxable Payrolls Under the Old Age and Survivors Insurance Program, First Quarter, 1947." This report contains tables of the number of establishments (here called *reporting units*) in the United States, classified by industry and by number of employees, and further classified geographically.

Table 25, entitled "Number of Reporting Units by Size Groups and Industry," is an extract from this report. It is extracted for 35 industry groups that seem likely to have a greater than average demand for office machinery. Unfortunately, the data in the Social Security Report omits some important industries whose employees were not covered in 1947 by social security benefits, such as interstate railroads, government-owned public utilities, educational institutions that are nonprofit or government-owned, etc.

Proportion of Engineers and Clerks

The second source of information for us is a report entitled "Occupational Characteristics: 16th Census of the United States: 1940: Population—The Labor Force (Sample Statistics)" published by the U. S. Government Printing Office, Washington, 1943, 256 pp.

This report is based on a 5 per cent sample instead of a complete census. Table 19 in this report shows the number of persons employed in the United States in March, 1940, in subdivisions for each occupation and for each of about 130 industries (that is, lines of business). Table 19 seems to be complete, covering government as well as every line of business.

TABLE 25

NUMBER OF REPORTING UNITS BY SIZE GROUPS AND INDUSTRY

Group No.	Industry Group	Number of Reporting Units: With 50 to 99 Employees	With 100 to 499 Employees	With 500 or more Employees
15	Building: general contractors	1159	789	111
16	General contractors, not building	789	574	42
20	Food and kindred products	2624	2355	327
21	Tobacco manufacturers	64	107	47
22	Textile mill products	1146	1932	636
23	Apparel, fabric products	3158	2230	145
24	Lumber and wood products	1862	1288	100
25	Furniture and fixtures	659	673	75
26	Paper and allied products	613	830	192
27	Printing, publishing, etc.	1162	976	181
28	Chemicals and allied products	954	944	230
29	Products of petroleum and coal	163	215	89
30	Rubber products	94	157	107
31	Leather and leather products	599	822	139
32	Stone clay and glass products	670	808	160
33	Primary metal products	742	1039	492
34	Fabricated metal products	1319	1544	384
35	Machinery except electrical	1416	1699	585
36	Electrical machinery	471	693	350
37	Transportation equipment	346	482	385
371	Motor vehicles and equipment (subgroup)	164	231	222
372	Aircraft and parts (subgroup)	42	51	51
38	Instruments	242	266	100
40	Interstate railroads*	1	1	0
432	Air transportation	67	78	39
46	Communication: tel. & tel., etc.	470	533	204
48	Utilities, electric and gas*	490	538	155
531	Department stores	1030	830	281

(continued on next page)

TABLE 25 *(continued)*

Group No.	Industry Group	Number of Reporting Units: With 50 to 99 Employees	With 100 to 499 Employees	With 500 or more Employees
532	Mail order houses	15	15	29
541	Grocery stores, with and without meat	430	357	149
60	Banks and trust companies	547	436	77
63	Insurance carriers	783	685	114
65	Real estate (including builders)	608	339	15
73	Business services, not elsewhere classified	782	470	38
82	Educational institutions and agencies*	57	17	1
	United States — Total (provided employees are covered by Social Security)	48,675	37,514	7,237

* Incomplete statistics.

With the information given in Table 19, we can estimate for each line of business the proportion of "affected engineers" and "affected clerks" (in 1940), where the term "affected" essentially means that it is conceivable or likely that the mental work that these persons do will either be largely carried out by or greatly assisted by computing machines.

To implement this concept of "affected," it is necessary to decide upon the specific meaning to assign to the term "affected engineers" in view of the statistics given in Table 19. The decision here made was that "affected engineers" in any line of business would be taken as: Civil Engineers, plus Mechanical Engineers, plus Electrical Engineers, plus Other Engineers, in that line of business. This number is shown in Column (4) of Table 26 on page 256.

In deciding upon the specific meaning of "affected clerks," it is evident that not all clerks will be affected by computing equipment. So the term "affected clerks" in any line of business was somewhat arbitrarily taken as: one half of Bookkeepers, Accountants, Cashiers, and Ticket Agents, plus all Office Machine Operators, plus one half of Stenographers, Typists, and Secretaries, plus all Other Clerical and Kindred Workers, in that line of business. This number appears in Column (6) of Table 26.

Of course, it would be better to use if we could statistics about engineers or clerks "who spend most of their time handling information in ways that an automatic computer could perform or aid"; but it is not to be expected that this sort of statistics will soon be provided in a report by a government bureau or industrial research body.

The total number of persons employed in each line of business as reported in Table 19 appears in Column (3) of Table 26. In Columns (5) and (7), the percents of affected engineers and affected clerks are shown; these percents are obtained by division of Columns (4) and (6), respectively, by Column (3).

This is the way, then, in which our Table 26, entitled "Per Cent of Affected Engineers and Affected Clerks," is derived from Table 19 in the report cited.

When the table corresponding to Table 19 but for the 1950 census instead of the 1940 census becomes available, we can improve our estimating, but for most lines of business, the change will probably not be great.

Besides the use of Table 26 to estimate potential market (in a way that will be explained in a moment), the percents of "affected engineers" and "affected clerks" there shown are a guide to the selection of those lines of business in which we should be the most interested, for the more affected engineers and affected clerks there are in any line of business, the more likely it will be that an automatic computer replacing, supplementing, or assisting them, i.e. affecting them, can be applied.

Estimating the Potential Market

With Tables 25 and 26, we can begin to estimate potential market. Suppose we take as an example "Rubber Products" (industry group no. 30) and size classification "100 to 499 Employees." Table 25 for "Rubber Products" shows 157 such plants. Suppose the average number of employees in such plants is 300. Table 26 for "Rubber Products" shows the per cent of "affected engineers" as 1.19 and of "affected clerks" as 9.79. We would expect $300 \times 1.19\% = 3$ "affected engineers" in this plant. Certainly with only three engineers there would appear to be hardly any market for an automatic computer for engineering uses. Also, we would expect about $300 \times 9.79\% = 30$ "affected clerks." Only a few of these would be now engaged in computing. Therefore, it is reasonable to conclude that in each of 157 rubber products establishments having from 100 to 499 employees, there would not be much of a market for an automatic

TABLE 26

PER CENT OF AFFECTED ENGINEERS AND AFFECTED CLERKS

(1) Group No.	(2) Industry Group	(3) Total Employment	Affected Engineers		Affected Clerks	
			(4) No.	(5) %	(6) No.	(7) %
20	Food and kindred products	1,066,060	3,120	0.29	81,090	7.61
21	Tobacco manufacturers	109,820	80	.073	5,600	5.10
22	Textile mill products	1,168,780	1,460	0.12	45,410	3.89
23	Apparel and fabric products	790,160	100	.013	29,180	3.69
24	Lumber and wood products	718,460	800	0.11	17,270	2.40
25	Furniture and fixtures	225,960	320	0.14	10,810	4.78
26	Paper and allied products	327,820	1,920	0.59	22,600	6.89
27	Printing, publishing, etc.	634,980	580	.091	83,810	13.20
28	Chemical products	440,820	6,880	1.56	45,150	10.24
29	Petroleum and coal products	202,180	6,220	3.08	27,450	13.58
30	Rubber products	158,200	1,880	1.19	15,480	9.79
31	Leather and leather products	369,260	120	.032	16,790	4.55
32	Stone, clay and glass products	337,820	2,000	0.59	17,830	5.28
33	Primary metal products	1,267,280	12,840	1.01	90,152	7.11
34	Fabricated metal products	275,540	2,060	0.75	19,890	7.22
35	Machinery (except electrical)	700,240	16,000	2.28	61,150	8.73
36	Electrical machinery	372,940	16,360	4.39	41,730	11.19
37	Transportation equipment	879,840	13,040	1.48	66,210	7.53
40	Railroads	1.103,680	5,540	0.502	144,320	13.08
432	Air transportation	22,320	380	1.70	3,310	14.83
48	Electric light and power	329,880	18,000	5.46	73,270	22.21
53	General merchandise stores	723,400	440	.061	20,490	2.83
54	Food stores (except dairy products)	1,334,600	40	.003	92,060	6.90
60 to 62	Banking and other finance	483,740	220	.045	221,240	45.74
63	Insurance	531,900	2,780	0.52	163,830	30.80
98G	Government	1,456,420	25,440	1.75	389,100	26.72
	All lines of business	45,381,360	245,700	0.54	3,005,180	6.62

computer, since the volume of mental work that a computer could do would be too small.

Rough Estimate No. 1

Suppose that on the average, an organization having 60 "affected clerks" will find it profitable to buy an automatic computer. What is the effect of this supposition using information that we have? For example, in insurance, the proportion of affected clerks is 30.8 per cent. Therefore any insurance company establishment with 195 or more employees would have 60 or more "affected clerks," and might be sold an automatic computer. A computation along these lines, supplemented with many approximations, is shown in Table 27, "Estimate of Number of Establishments with 60 or More Affected Clerks."

The result of this computation is that about 8000 organizations have 60 or more "affected clerks," and so we could estimate that some 8000 automatic computers could be sold to them over the next 5 or 10 years. Of course, some would not buy but others might buy two or more.

Can we check this calculation by other estimates and by general reasoning? Here is a second rough estimate.

Rough Estimate No. 2

Table 25 shows 7200 establishments with 500 or more employees, and 37,500 establishments with 100 to 499 employees. These are incomplete counts. Suppose we increase them by 10 per cent, obtaining 8000 and 40,000. Suppose that 1/2 of the first group and 1/8 of the second group can be sold automatic computers over the next 5 or 10 years. Then 4000 plus 5000 computers would be sold in 5 or 10 years, or from 900 to 1800 a year. 9000 by this estimate compares with 8000 by the preceding estimate.

General Comments

If the average price of a computer were $100,000, then $90 to $180 million a year would be spent for automatic computers. This figure contrasts with the annual sale of desk calculating machines which for 1951 was about $50 to $60 million. They are not unreasonably related.

Why is there such a wide gap between (1) the value provided by the application of automatic computing machinery, estimated as 10 to 20 billion dollars a year as we computed in Section VII:1 and (2) sales of perhaps $180 million a year? We would expect that the first figure would be very large, because it estimates the advantages of an automatic computer in terms of equivalent human beings. Suppose the overall factor of advantage in work done by an automatic computer was 100 to 1; then the $180 million of annual sales would correspond with $18 billion of equivalent human labor power yielded.

TABLE 27

ESTIMATE OF NUMBER OF ESTABLISHMENTS WITH 60 OR MORE AFFECTED CLERKS – COMPUTATION[a]

(1) Industry Group	(2) Percentage of Affected Clerks	(3) Minimum Size of Plant to Have 60 Affected Clerks	(4) Estimate of Number of Plants Over Minimum Size[c]	(5) Result, (5)=(4)
60 to 62, Banking and other finance	45.7	131	77+.8(436)	426
63, Insurance	30.8	195	114+.7(685)	594
98G, Government	26.7	225	?	700[d]
48, Electric light and power	22.2	270	155+.5(538)	424
432, Air Transportation	14.8	405	39+.2(78)	55
29, Petroleum and coal products	13.6	441	89+.1(215)	111
27, Printing, publishing, etc.	13.2	455	181+.1(976)	279
40, Railroads	13.1	458	?	80[d]
36, Electrical machinery	11.2	536	350(.95)	333
28, Chemical products	10.2	588	230(.9)	207
Other industry groups	4.6[b]	1304	6000(.7)	4200
Omissions from Table 25				600[d]

Estimate of number of establishments with 60 or more affected clerks,

—total:	8009
—rounded off:	8000

[a] The high clerical groups are calculated separately; the rest, all together.

[b] Computed from Table 26 figures by finding effect of removal of high clerical groups.

[c] Estimated from Table 25; basis of estimate indicated in column (4).

[d] Roughly estimated from general reasoning.

It would be very easy to criticize the foregoing data and reasoning, and to make a long list of factors that have been ignored or have not been properly considered. A few examples: selling a computer depends a great deal on whether it is really a general purpose computer, and can properly perform sorting and looking up; the prices of powerful general purpose automatic computers actually sold do not yet average $100,000 but a good deal more; the first year in the five or ten year period being considered is likely to amount to a good deal less, perhaps a half or a third of the later years of the period; there is hardly any justification for some of the fundamental factors used above, such as "60 affected clerks"; etc.

But by and large it appears that a framework for making an estimate of the market for automatic digital computers has been expressed in this chapter. And other and much better estimates can be made later on using this framework as a pattern to build on and modify.

VII:3 THE ATTITUDES OF PROSPECTIVE BUYERS TOWARDS AUTOMATIC COMPUTING MACHINES

In Sections VII:1 and 2, we have estimated roughly how much value automatic computers might yield, and what prospective sales might occur. But it is possible to add still more information about the market for automatic computers by reporting how prospective users have reacted to the idea of buying and using them.

Presented below is a summary of about sixty reports on a number of contacts made expressly for the purpose of determining the attitude of prospective buyers towards automatic computers and particularly small automatic digital computers. This information gives a fairly vivid and typical picture of prospective buyers.

Of course similar but better information about thousands of contacts with prospective buyers resides in the files of each of several of the largest manufacturers of automatic computing machinery. But these files, extensive as they are, are of course confidential, since the information about those contacts is closely associated with the high standing of these manufacturers in competition. Therefore one can't go to one of these large companies and say: "I would like to have a summary of all the contacts you have made in the last four years in the rubber products industry, and the reactions of prospective buyers. I am interested in selling automatic computers to them." If one did make such a request, the answer that would be given is obvious.

The sixty organizations were contacted and interviewed in order to find out statistics, evidence, and opinion of the usefulness of computers to them. These contacts occurred mainly in 1949, 1951, and 1953; and although several years have passed, by and large not much change in attitude is to be expected since the attitude is determined by facts of self-interest.

In a number of cases most of the information desired was procured. In other cases some of the data were not obtainable, as for example the total number of employees in a case where a representative of an organization working for the military stated that the number of its employees was classified.

An effort was made to observe companies in many different industries. On the other hand, 65 observations divided over 30 industries are insufficient for numerical conclusions to be drawn. In fact, in many cases the only conclusion that can safely be drawn from so small and so inadequate a sample, is a conclusion of the type that something or other is either possible or impossible. Before proceeding to the report of the sample, we can make some general remarks.

Saving

The biggest factor in the attitude of a great many prospective buyers is naturally the question whether a potential saving exists. If a really substantial saving can be shown by the use of an automatic computer taking into account the costs associated with operating it, then the buyer is definitely interested.

The argument that a company can get a great deal more information than it is now getting is not very strong in many cases. A hard-shelled buyer will often say that he knows of cases where punch card machinery has been a mistake: machines that did not justify themselves for the work for which they were originally acquired have gathered unnecessary work to make a show of being justified.

Demonstrating a saving is often hard. A true comparison of the cost of the existing method of doing a certain job and a proposed method of doing it using automatic computing machinery entails considerable work in gathering data and more work still in making an intelligent and fair analysis.

A number of different questions have to be studied and answered: What is the cost of people in the present system? in the proposed system? What is the cost of people to prepare and code problems for the automatic computer? If one machine is available only for rental, and another only for sale, how do you compare their prices—is four years of rental the equivalent of a one-sum payment? Just how should one determine the value of the information which the automatic computer might produce? Would it be better to arrange for computation with a computing service, and not buy a computer?

In a large organization, the amount of work to change over from one system to another system may be extremely great. The second system may be clearly better; yet sometimes the existing system is large to begin with, has been in operation for a number of years, and has become so ramified and so well adjusted and corrected that it is like a living organism in the fineness and complexity of its features. It takes a great deal of careful, perceptive observation, investigation, and planning to make the changeover a success, especially if there is some opposition from old line supervisors.

Progressiveness of Management

Another important factor affecting the possibility of sale is the attitude of the management of the company, progressive or conservative, towards making changes in the procedures and equipment used in an organization. It will be difficult to sell an automatic computer to a management that is substantially conservative, especially if there are at least some good reasons in their experience for conservatism.

The attitude of management not only affects the chance of selling an automatic computer but also has a considerable effect on the length of time from the first contact seeking sale to the completion of the sale. In some cases even after a contract of sale has been signed, the conservative branch of the management generates enough hesitation and lack of confidence so that it is rescinded. This is more likely to occur if the contract, as it usually does, contains rather arduous conditions upon the manufacturer of the computer, such as specifications for very reliable performance of the equipment, which are subsequently not fully met.

Summary of Reports on Contacts

Other factors affecting the attitudes of buyers are reflected in the following summary of reports on a number of contacts. The general plan of each report is: type of company (year when contact made) / number of employees / number and types of computing machinery now used / notes on computing now done / beliefs, opinions, remarks. Where information was not available, it has been omitted.

Aircraft manufacturing company (1949) / ? employees / have an automatic computer (electronic analog type, general purpose), and some other machines such as desk calculators / engineering and design calculations for guided missiles / "if we were to buy another computer, it would have to have easy coding and be better than our present one."

Aircraft manufacturing company (1949) / 4500 employees / have 62 adding machines, 63 desk calculators, 44 punch card machines / calculations: engineering, wing load, stress and strain, bills of materials, payroll, etc. / "would be interested in an automatic computer only if really useful to us."

Aircraft manufacturing company (1951) / ? employees / have several automatic electronic analog computers (general purpose), etc. / engineering and clerical calculations / "an automatic digital computer would not be a worthwhile supplement to the desk calculators and punch card machines now used."

Airplane motor manufacturer (1951) / 25,000 employees / ? desk calculating machines, ? punch card machines, 5 electronic calculating punches, 1 card programmed calculator / engineering and clerical calculations / "an automatic computer might be useful to us."

Automobile manufacturer (1949) / 2500 employees at two main plants / 150 adding machines, 100 desk calculators, 20 punch card machines / cost accounting, quality control, financial analyses, sales, statistics, payroll. Sorting and look-up are important. In the cost accounting department, computing machinery needs to pay for itself in 6 months / "interested in an automatic computer only if really useful to us."

Automobile manufacturer (1949) / 21,000 employees, of which about 850 do a significant amount of computing / 400 comptometers, 300 desk calculating machines, 650 punch card machines, 0 electronic calculating punches / accounting, time study, statistics, planning, budget, engineering calculations, distribution. Sorting and look-up are important / "interested in an automatic computer only if really useful to us."

Bank, head office (1951) / about 4000 employees / 200 desk calculators, a "large installation" of punch card machines / accounting, payroll, statistics, financial payments, etc. / "a certain amount of calculating could undoubtedly be centralized; we favor renting this new type of machine rather than purchasing; we believe it unwise to consider purchasing until the period of initial use is passed."

Business service (1951) / 50 employees / 27 desk calculating machines, 5 punch card machines including 1 electronic calculating punch, 1 card programmed calculator / amortization schedules for clients, financial payments, etc. / "a small automatic digital computer would be useful to us; it would be more economical; – it is important to have an adequate service organization for the computer."

Business service (1951) / 250 employees / 15 desk calculators, 8 punch card machines, including 1 electronic calculating punch / inventory control, cost accounting, calculations and tabulations for customers, etc. / "a small automatic digital computer could probably be used... especially if the machine could print the answer in the place where it would be used."

Business service (1951) / 700 employees distributed over several locations; 100 employees in statistical and calculating departments in head office / 6 desk calculating machines, 35 punch card machines, 2 electronic calculating punches / payroll calculations, inventory control, tabulations, etc., for customers / "don't know if a small automatic digital computer would be useful to us."

Chemical manufacturing and distributing company (1951) / 80,000 employees; 20,000 in head city and vicinity, 9 manufacturing departments, 13 auxiliary departments, 85 plants / engineering research laboratory has 80 engineers, 45 other employees / 1100 desk calculating machines, $500 thousand yearly rental for punch card machines; engineering laboratory has 6 desk calculators, no punch card machines / accounts receivable ledgers, payroll, salary records, sales analyses, etc. / To solve engineering problems company has rented time on outside differential analyzers. Believe "the company could usefully employ a small automatic digital computer, but before it would buy any, it would rent time on the equipment and test to make sure that it would save more money than the 25% return this company can realize on a new chemical plant."

Chemical manufacturing and distributing company (1951) / 20,000 employees in about 30 plants and 50 branch offices / 1000 desk calculating machines, 40 punch card machines/payroll, accounting, etc. "No money is spent" on engineering calculations. / "a small automatic computer at moderate price might increase our production and lower costs."

Communication operating company (1949)/21 subsidiaries operating 1 million telephones in 19 states, with 14,800 employees; the three largest subsidiaries have 3100, 2100, and 1000 employees; / the engineering departments use slide rules; a subsidiary with 97 employees is the only one using punch card machines, and is just beginning / "any automatic digital computer to be useful would have to take in information direct from the telephone equipment."

Communication, research laboratory (1951) / about 3500 employees / 50 to 100 desk calculating machines, 20 punch card machines, card programmed calculator, general purpose computers, one analog, one digital / engineering and clerical calculations / "one needs a whole spectrum of machines in the laboratories; if the small automatic computer is easy to program, it would be useful; high speeds are nonsense; a mathematician wants an automatic computer for personal use; the labor of coding must be minimized; we want a large number of small problems solved; even now a lot of things are not done because the computing is impossible."

Department store (1949) / ? employees / 1700 pieces of office machinery including typewriters, no punch card machines / accounts payable, distribution of purchases as charges to 400 store departments, distribution of sales similarly, payroll, accounting, sales audit, accounts receivable. Sorting and look-up are important/ "interested in an automatic computer only if really useful to us."

Department store (1949, 1951) / 10,000 employees (25,000 at Christmas); some 700 have some computing to do/315 adding machines, 65 bookkeeping machines, 15 desk calculating machines; punch card machines 30 in 1949, 14 in 1951; no electronic calculating punches / sales audit, sales compilation, accounts payable, banking transactions, merchandise statistics, merchandise control, payroll, etc. Sorting and look-up are important / "we are doubtful that an automatic digital computer would be useful to us."

Department store (1949) / 1700 employees in 6 stores over metropolitan area; 65 employees in the Central Accounting Dept., and 85 employees in the Accounts Receivable Dept. and Credit office /

22 comptometers, 4 desk calculators, 11 punch card machines / accounts payable, payroll, sales analyses, expense control, cost inventory, mechanizing the stock ledgers, etc. Sorting, look-up, and conversion into and out of punch cards are important requirements for any automatic computer / "interested in an automatic computer only if really useful to us."

Electrical apparatus manufacturer (1949) / 200,000 employees in over 120 plants; 40,000 employees in central plant / in central plant $250 thousand yearly rental for punch card machines; many desk calculating machines and small computers; several large automatic computers / engineering and clerical calculations / "willing to buy or rent equipment from any supplier if it is competitive."

Electrical machinery manufacturer, industrial laboratory (1951) / 10 employees / 1 desk calculator, 1 electronic calculating punch, 1 card programmed calculator, 1 big analog computer / engineering calculations / "a small automatic digital computer would be useful" because "it would minimize prolonged manual desk calculator operations."

Fire insurance company (1949) / 450 employees / 8 desk calculating machines, 10 punch card machines / clerical calculations / "don't know how we would use an automatic computer; our calculating work has been a comparatively simple matter, so much so that we never thought we could use any kind of punch card multiplier or computer to advantage."

Food products company (1949) / 18,000 employees in many locations; 1400 in head office, 2000 in largest plant / 65 punch card machines in head office / payroll, billing, sales statistics, tax totals, inventories, comparative operating statements, etc. Sorting and collating are important / "interested in an automatic computer only if really useful to us."

Food products company (1949, 1951) / 200 employees in this head office; 45,000 employees in very many plants and branch offices; in the central office, 4 desk calculating machines, no punch card machines / employee payroll, farmer payroll, milk grade premiums, inventory control, sales statistics, etc. / "an automatic digital computer would not be useful here, though some of our larger subsidiaries might consider it."

Government agency (1951) / 4700 employees / 48 desk calculating machines, 849 punch card machines including 2 electronic calculating punches / accounting calculations for millions of people / "a small automatic digital computer would not be useful; our computation is not very complex or extensive; major part of our job is punching cards and recording to accounts. We need electronic equipment that can sort at high speed and provide rapid access at random to stored data. ''

Government commission, financial reports division (1949) / 30 employees, of which 10 compute; 7 adding and calculating machines, 8 punch card machines / statistics on corporate finances / sorting, and short sequences of calculations, are important / ''doubtful that a small automatic digital computer would be useful.''

Government commission, branch office (1951) / 400 employees at this location / 40 desk calculators, no punch card machines / ''an automatic computer would not be useful in this office at present... not sufficient work load.''

Government computation laboratory (1953) / ? employees / have built a very high speed automatic computer for their own use / ? other machines / scientific and engineering calculations / wanted an automatic computer and made it for themselves.

Government computation laboratory (1953) / about 25 employees / 20 desk calculating machines, a number of punch card machines, a large high-speed automatic digital computer / scientific and engineering calculations / wanted an automatic computer and obtained it from another government agency.

Government computation laboratory (1951) / 100 employees / 20 desk calculating machines, 26 punch card machines, including 6 electronic calculating punches, large automatic digital computer / scientific and engineering calculations / ''doubt that a small digital computer would be useful to us. Large problems are handled on our big digital computer, small ones by hand.''

Government observatory (1951) / 110 employees, of which 50 do some computing / 30 desk calculating machines, 9 punch card machines, including card operated typewriter, no electronic calculating punch / astronomical computing / ''believe a small automatic digital computer would be useful if servicing is infrequent and quickly available.''

Life insurance company (1951) / 700 employees / 75 desk calculators, 32 punch card machines / clerical calculations, etc. / ''a small automatic digital computer would not be useful in our work as constituted at present; we operate on a plan of individuals following through complete operations with occasional computations included.

We have not centralized our computing work. Our office is largely mechanized on punch cards, and we have no desire at this time to upset a complicated system of controls."

Life insurance company (1951) / 10,000 employees in the central home office / 653 desk calculators, 620 punch card machines including 9 electronic calculating punches / clerical calculations, sorting, look-up, are important / "a small automatic digital computer might be useful to us, as well as a large one."

Life insurance company (1949, 1951) / 6300 employees in the home office of whom about 600 do some computing / 1100 adding and bookkeeping machines, 330 desk calculating machines, 366 punch card machines, including 9 electronic calculating punches / payroll, statistics, mortality studies, policy valuation, cost accounting, cost allocation, dividend allocations, rate book and policy value calculations, etc. Division is rare; more advanced mathematical work almost never occurs. Sorting and look-up are important / "automatic digital computers might be useful to us."

Life insurance company (1953) / 14,000 employees in the home office / very many desk calculators and punch card machines / clerical calculations / "purchasing a large-scale automatic digital computer capable of doing quantities of clerical work."

Life insurance company (1951) / 1650 employees in home office / 129 desk calculating machines, 40 Moon-Hopkins bookkeeping machines, 50 punch card machines, including 1 electronic calculating punch / clerical calculations / "an automatic digital computer might have several possible applications, but we would have to program it to evaluate it."

Life insurance company (1951) / ? employees / 86 desk calculating machines, 26 punch card machines, 0 electronic calculating punch / clerical calculations / "a small automatic digital computer might be useful because it should turn out work faster at a lower cost."

Machinery manufacturer (1951) / over 500 employees / 34 desk calculating machines, 11 punch card machines, including 0 electronic calculating punches / engineering and clerical calculations / "an automatic digital computer is not practical for us in view of the nature of our work."

Machinery manufacturer (1949) / 9000 employees; 24 employees in Central Tabulating Dept. / 5 adding machines, 27 punch card machines / payroll, statistics, cost accounting, labor distribution, material distribution, accounts payable, sales analysis, property accounting, etc. / "interested in an automatic computer only if really useful to us."

Machinery manufacturer (1951) / 19,500 employees; 280 employees in the works accounting department, which does 80% of the computing in company / 30 comptometers, 47 desk calculating machines, 90 punch card machines including 2 electronic calculating punches / mainly clerical calculations; sorting and look-up are important / "an automatic digital computer must tie in with punch card machines."

Mail order house (1951) / over 10,000 employees / a great number of desk calculators, a considerable number of punch card machines, 0 electronic calculating punches / have quantities of clerical work to do involving filling orders, sorting, looking up, totaling / "doubt that we would buy an automatic computer without the ability to sort and make look-ups."

Mail order house (1949) / over 10,000 employees / the whole company handles about 40 million orders a year in 40 departments with 10 catalogues outstanding; main question is "What are sales each day in each department derived from each catalogue?" Present mail order statistical work uses 30 girls with Burroughs calculators and NCR cash registers model 2000. All this work could be saved and much better information obtained if computing machine input could be a byproduct of an existing order operation such as the biller's operation when the order is billed.

Market research organization (1949, 1951) / 2000 employees in 5 locations; 600 employees in head office, of which 300 do some computing / 100 adding machines; desk calculators, 25 in 1949, 10 in 1951; 100 punch card machines including 6 electronic calculating punches / sorting and look-up are important / "believe an automatic digital computer would be useful because it would speed up handling of figure work and would reduce costs... price we would pay depends on the saving."

Meat products company (1951) / 75,000 employees, 36 plants, 229 branches; 1,700 in main office; 10,000 in main plant / considerable punch card machinery, etc.; sorting and look-up are required; "endless comparisons" for internal control / "Our company recognizes the need for automatic computing equipment, but feels that greater progress can be made with punch card equipment, which has been installed at nine locations, with six more contemplated; we are acquiring electronic calculating punches."

Oil company, exploration department (1949) / 125 employees; 7 employees doing computing / 3 adding machines, 5 desk calculating machines, 0 punch card machines / algebraic equations, differential equations, numerical integration, matrix multiplication, etc. Sorting is important. Have rented time on an automatic electronic digital computer. / "Our needs can probably be met by aggregates of the computers now on the market."

Oil producing and distributing company (1949) / over 40,000 employees all over the world / many separate installations of office machinery / inventory valuation, profit and loss statements, timekeeping, payroll, pension plan calculations, oil flow problems, chart recording and interpretation, service station ticket accounting, etc. / "would be interested in an automatic computer if it were really useful."

Oil producing and distributing company, engineering research department (1949) / 49,000 employees in many plants; 58 in engineering research / "we get time on punch card machinery when we need it. The market research division rents $25 thousand yearly of punch card machinery" / "probably not interested in an automatic computer."

Oil producing and distributing company, research division (1949) / 40,000 employees in whole company; 1600 employees in this division, 1000 in the central research division, 600 all around the world (geophysicists) / engineering calculations / "for engineering problems our demand is for a computing service rather than for machines themselves."

Paper products company (1949) / 8400 employees in 6 plants / at 4 of these plants there are small punch card installations; total number of tabulators is 5 / sales statistics, accounts receivable, payroll, accounting, stock control, inventory, etc. Sorting and lookup are important / "doubt that an automatic computer would be useful to us."

Process engineering consultants and designers (1949) / 1300 employees, of which about 300 are engineers and about 800 are draftsmen / 25 desk calculating machines, some Burroughs bookkeeping machines, no punch card machines / engineering calculations / "The engineers use mostly slide rules; it will be some time before the mathematical stages of their work become advanced enough to justify an automatic computer."

Public utility (1949) / 30,000 employees / have a large installation of punch card machinery / "policy of company is to give out no information."

Public utility (1949) / over 10,000 employees / punch card and other machinery / clerical calculations / "We are looking for extreme high speed and high capacity to handle 1.8 million bills and 0.6 million cost entries each month. A very powerful automatic computer would be useful for us."

Public utility (1951) / 370 employees / 78 adding machines, 9 desk calculating machines, 45 punch card machines, including 1 electronic calculating punch / payroll, cost accounting, statistics, billing, etc. / "a small automatic digital computer would be useful if it had more storage than the electronic calculating punch and no less speed."

Railroad (1949) / 17,000 employees altogether, of which about 700 are engaged in computing / punch card and other machines / passenger and freight car accounting / auditing disbursements and receipts; statistical work; a vast amount of sorting and totaling / "an automatic digital computer would hardly be useful to us."

Railroad service organization (1951) / 27,000 employees in 136 locations; 1500 at the central location / 100 listing adding machines, 30 National Cash Register bookkeeping machines, 12 desk calculating machines, 20 punch card machines, including 1 electronic calculating punch / a great amount of sorting and totaling and other clerical calculations / "an automatic digital computer might be useful, but we would want to know more about it. Our policy is to install equipment on the basis of the saving that will result. Usually we expect the machine to pay for itself in a year or two."

Rubber products company (1949) / 2500 employees / 150 adding machines, 50 desk calculators, 37 punch card machines / payroll, statistical work, cost accounting; no advanced mathematical work; sorting and look-up are important / "interested in an automatic computer only if it would be really useful to us."

Rubber products company (1949) / 12,500 employees in main plant, of which some 600 employees do some computing / 400 adding machines, 50 desk calculators, 100 punch card machines / cost accounting, payroll, engineering, statistical work, scheduling; sorting, look-up, finding percentages, are important; very few complex calculations / "interested in an automatic computer only if it would be really useful to us."

Rubber products company, research center, (1951) / ? employees

/ "Have only one or two standard calculating machines, made available to our scientists when their work requires it." / "not interested in an automatic digital computer."

University, bursar's office (1949) / about 40 employees / 27 punch card machines, etc. / payroll, general accounting, cost allocation, purchase order accounting / sorting and look-up are important / "hard to see how an automatic computer would be useful to us."

University, commission for economic research (1949) / 25 employees / 4 human computers, 4 desk calculating machines, no punch card machines / "have many problems we cannot now solve because of expense: matrices; maximum likelihood functions of many variables; stochastic difference equations; etc." / "Would like a small automatic digital computer if faster and cheaper than competitive machinery."

University, computation laboratory (1952) / 20 employees / 8 desk calculating machines, 5 punch card machines, 0 electronic calculating punches, one large automatic digital computer / engineering and scientific calculations / wanted and have obtained an automatic computer.

University, statistical laboratory (1951) / 40 employees / 15 desk calculating machines, 6 punch card machines, 0 electronic calculating punches / analysis of variance, regression, matrices, numerical integration, matrix multiplication, etc. / "a small automatic digital computer might be useful to us depending on the degree the machine is not inoperative for repairs."

University, statistical laboratory (1951) / 60 employees / 20 desk calculators, 6 punch card machines, 0 electronic calculating punches / statistical calculations / "a small automatic digital computer could be useful in many calculations not involved enough to warrant a complicated machine."

University, technical school (1951) / 100 employees / 10 desk calculating machines, 0 punch card machines / some scientific and engineering calculations / "a small automatic digital computer would be useful because of some time saving, but it would apply to only a portion of our work."

University, government technical school (1949) / staff of 80, and 350 students / 15 desk calculators, 0 punch card machines / calculations in statistics courses and ballistics courses / "Our computations are not of the type we wish to avoid."

VII:4 APPLICATIONS OF AUTOMATIC COMPUTING MACHINES IN BUSINESS

In certain kinds of businesses a good deal of information is necessarily handled. Typical of these businesses are:

- Life insurance
- Casualty insurance
- Banking
- Market research
- Military supply corps
- Mail order
- Department stores
- Railroads
- Airlines
- Government agencies

These businesses are not only the logical users of automatic computing machinery but also the chief businesses that have actually ordered automatic computers.

In addition, in nearly every large organization certain departments are assigned as their main duty the handling of a large amount of information and the producing of answers to questions, such as:

- Payroll computation
- Cost allocation
- Sales analysis
- Production scheduling
- Purchase order accounting
- Materials ordering
- Stock control
- Financial statements
- Indexes of company progress

These departments are logical areas to use automatic computing machinery, depending as usual on the quantity of information to be handled.

We shall first give a rather full description of some of the problems involving the application of automatic computers, and then cover a number of other problems with considerably less detail.

Payroll

Calculating and paying periodical wage and salary checks to the employees of a company seems at first glance not very difficult to do. You make sure how long a man has worked, look up his rate of pay or salary, multiply out, and pay him. But in many companies both large and small, it is not so simple as this.

To compute payroll, two kinds of information about each employee are needed: information or data which is fairly constant from one pay period to another, such as his rate of pay (changing only sometimes); and information which may vary in every single period, such as the overtime hours he has worked. Let us call the first file the master file, and the second file the current file. The master file will remain in the paymaster's department, but the current file will need to be assembled shortly before each payday from reports made by the line departments. Information which may be contained in the master file is voluminous and is shown in Table 28.

TABLE 28

PAYROLL – DATA IN MASTER FILE

I. Employee Data
   - Employee's name
   - Employee's number
   - Union number or identification
   - Sex
   - Date of birth
   - Date of employment
   - Dates when he was laid off or called back to work
   - Department
   - Job title

II. Pay Data
   - Regular pay rate
   - Any special pay rates which may apply

III. Employee Deduction Information
   - Group insurance deduction if contributory
   - Group hospitalization deduction
   - Union dues
   - Contributions to Community Chest if deducted
   - Deductions for purchase of United States Government bonds
   - Information for computing deductions for income tax: Federal, state, and city, if any
   - Information for computing Federal Old Age Benefit tax, such as total wages paid to the current date in the year not exceeding $3600
   - Information for computing deduction of pension plan contributions
   - Special deductions such as unpaid bills, corrections for past errors, records of deductions that could not be made currently because the employee was not at work, etc.

The information provided by the current file consists often of hours worked during the pay period, subdivided by the classes of work for which the employee receives different rates of pay. The current file will also furnish, if the employee works on an incentive pay plan, the number of pieces of each kind produced.

Ordinarily, the automatic computer will arrange the information in the current file into the same employee number order as the master file. The computer will then refer to the information in the master file that pertains to each employee, and combine it with current information. Next it computes the gross pay, each deduction whether fixed or variable, and the net pay. It will also compute new cumulative totals such as total hours worked to date, total pay on which Federal Old Age Benefit Tax has been collected, etc., and store them in the master file.

The computer is not usually required to print out the results produced; rather they are transferred to a medium like magnetic tape, which is then used to control an electric typewriter or printer that actually prepares the paycheck. We may estimate that for each employee the computer will take in or put out some 50 pieces of information and perform some 30 or 40 arithmetical and logical operations.

Interline Ticket Sales on a Railroad

A large amount of information handling is carried out by railroads. Let us consider one of the "accounts payable" problems. One of the things that a railroad does is sell to its passengers tickets good for traveling on to connecting railroad lines. These "interline tickets sales," as they are called, are apportioned by the selling railroad to the "foreign" railroads, and it is duty bound to pay the proper portion of each fare received to each foreign railroad.

Now in order for the central accounting office of the railroad to carry out this job, the station agents make reports and attach to them the ticket stubs showing the fares collected. The reports come in daily, weekly, or monthly depending on the volume of interline passenger ticket sales. In the case of one railroad, 20,000 such ticket stubs are collected each month by the central accounting office.

The central accounting office has to produce the answers to such questions as the following:

1–Did the agent report the proper amount? Answer: Total the stubs that he sends in and compare them with his report.
2–How much money is to be paid to each foreign railroad? Answer: Sort the stubs by foreign railroad; total them; look up the apportionment schedules; and calculate the amount to be paid to the foreign railroad.
3–Are you sure that the total amount apportioned to foreign railroads on any fare collected is less than the fare? Answer: Verify to be sure.
4–How much has our own railroad earned? Answer: From the total sales subtract the amounts paid to foreign railroads.
5–Are the figures for this month reasonable in relation to the last few months and this time last year? Answer: Prepare the monthly report of Interline Ticket Sales.

This is a substantial amount of work for clerks, and is meat for an automatic digital computer.

Data Processing in a Life Insurance Company

Automatic computing machinery can be applied extensively in life insurance companies, provided that many presently separated clerical operations are recombined.

In the usual life insurance contract (policy) an insured person (policyholder) makes regular payments (premiums) to the company in return for which the company promises to pay certain benefits at a certain time (maturity of the policy) to him or to his beneficiaries. If the insured stops paying premiums, then his policy ordinarily has some value, which may be paid to him in cash (cash surrender value option) or may be given to him as insurance for the full amount lasting for a certain time (extended insurance), or as insurance for a smaller amount fully paid and lasting to the original maturity date of his policy (paid up insurance). The insured may also if he wishes borrow money from the company on the security of the cash value of his policy (loan option). He may elect that the value of the policy at its maturity shall be paid over a time to his beneficiaries (settlement option). According to law, the company must usually notify the insured whenever his periodical payments are due (send out premium notices), and tell him of annual dividends payable to him (dividend notices), which he may dispose of in certain ways, either in cash or by adding to his insurance (dividend options).

As a result of the great growth of the life insurance business over the last 70 years, and its developing complexity, nearly all life insurance companies containing upwards of 80 employees in their home office (the largest company has about 14,000 employees in its home office) have become organized into fine subdivisions of clerical labor. Consequently, the usual departments are: Surrender Department; Extended Insurance Department; Paid Up Insurance Department; Loan Department; Settlement Options Department; Premium Notice Department; etc. Of course, there are also some staff departments: the Actuarial Department that manages the technology of the insurance business, the Law Department, etc. There is also a Valuation Department, which is responsible for proving to the state insurance regulatory bodies that the company is holding the appropriate amount of reserve for every single policy. It is quite impossible for any single human being to know all that a large life insurance company does or can do about one policy, including all the unusual cases. Because the clerks frequently have to refer to files, there may be from 8 to 12 major files in which all policies of the company are entered, such as the valuation reserve file, the premium history card file, the dividend card file, etc.

This trend has been called the *development of fractured operations*. Yet in order to apply a big automatic computer, what is needed is the *development of combined operations*, where all calculations and files for a policy are recombined into a single operating point. The trend has to be reversed. It is as if all the policies in a certain interval of policy numbers were assigned to a single clerk who had to perform all the necessary transactions upon all of them. For example, the automatic computer would take in the data in regard to a policy being surrendered, compute the cash value from the original actuarial formula and data, interpolate for the premium paid-to-date, multiply by the amount of insurance, deduct any loans, compute the interest on each loan and deduct that, credit the value of any dividend accumulations and any premiums paid in advance, and record on a magnetic tape instructions for typing out the check to the policyholder in payment of the net value of the surrendered policy.

Paid up values, extended insurance, dividends, etc., could all be calculated automatically when desired; the machine would store the formulas and the rules, and only the policy data for the particular case in question would need to be given to the machine. Where accounting is required, the machine could record accounting entries automatically.

Another use for the automatic computer would be to prepare premium notices automatically. The machine would store the history of premiums paid, make appropriate changes in the insured's address, determine when the premium notice is to be prepared, store the dividend formula, compute the dividend for the policy, subtract the dividend from the premium in cases where the net cost also is to be shown on the premium notice, and type out the premium notice. The machine would easily remember and obey such rules as: "Where the dividends are being accumulated, do not show the dividend on the premium notice." If any loan was outstanding on the policy, the machine, storing the loan interest rate, and being given the loan data, could compute the number of days duration of the loan, apply the interest factor to the loan, find the accumulated loan and interest, and put this also on the tape for the premium notice. The premium history record on the magnetic tape could be quickly brought up to date from time to time for premium payments, changes of address, and all other changes of status.

One of the regular departments in a life insurance company is the Underwriting Department, which is charged with the duty of appraising the applicants for life insurance and deciding whether or not the health and other circumstances of the applicant make him a reasonably good risk for the company to insure. In order to carry out its duties, the department usually compiles a rule book of some 5000 rules, so that most of the actions of the company can be carried out by "lay" underwriters (clerks) and fewer than 1 per cent of the applications have to be referred to the medically trained underwriters. With a book of 5000 rules translated into machine language, the automatic computer could look up the sections of the rules which apply to any particular application of insurance. Underwriting carried out by an automatic computer could be more complete, more accurate, and considerably more complicated and flexible than that carried out by clerks.

It may be argued that there is no room for judgment in such a procedure. If the judgment can be expressed in words that a clerk can apply, and if the words can be translated into the language that the machine knows, then certainly the machine can carry out the judgment too. In fact, one of the virtues of the machine, as for example has been shown with punch card machinery in recent years, is to compel a definiteness of thinking which is not always easy to reach.

Pension Plans and Consulting Actuaries

An important part of the information operations for employee pension plans is carried out by clerks and actuaries, either in large insurance brokerage firms, or firms of consulting actuaries as such. In fact, most of the technical work done on the pension plans for employees of large companies is guided by such firms.

A typical calculation which a consulting actuary has to perform is the following: The treasurer of the ABC Company with 5000 employees comes into the actuary's office and says, "We expect to establish a pension plan for our employees. We have had some discussions with the union. They want this kind of formula for the pension benefit. We think this other pension formula would be better. Then there are these other half dozen formulas which we in the company would like to look into. What will each of these benefit formulas cost us?" The consulting actuary says: "We can compute the costs on several reasonable assumptions. Please give us the data on your employees: date of birth, date of employment, sex, classification such as salary or hourly, present salary rate or wage rate. This is a fair amount of calculation, and it will take us at least a couple of weeks to make the valuation and estimate the costs." The treasurer says: "By the way, we think we have rather heavy turnover in the first few years of employment. We'd like you to take that in account." The actuary says, "Then I shall have to have data on your terminations, for say the last three years, and the calculations will take us a little longer."

In the first part of the calculation, determining the effect of the pension plan formula on each employee, the actuary has to take that employee's data, and insert that into the formula, determining the amount of pension benefit. He then has to select the appropriate actuarial factors, apply them to the proposed benefit, and obtain the expected cost of the benefit. Approximations are frequently used. Often the expected cost will be finally expressed as so many cents per hour or such and such a per cent of payroll.

Calculations of this kind are already being done on punch card machines, especially in cases where the formulas are complicated and the number of employees is large. But they could be done much better and much faster on an automatic computer, because the complications of the formula are no longer substantial obstacles. At least one consulting actuarial firm has ordered an automatic computer for such purposes as these.

Cost Allocation

"Cost Allocation" or expense analysis is the problem of applying formulas to overhead and indirect costs in order to apportion them appropriately among the products being produced, so as to determine the actual cost of producing each product. In this way one can compute a product's true cost (if such can exist), compare it with the sale price, and determine the profit.

On one occasion, a big chemical company perplexed by this problem set it up in the form of a large set of simultaneous equations, requiring about 400,000 arithmetical operations for their solution. Then they took the problem to an IBM service bureau that had a Type 701 automatic computer, and there solved the problem in a few hours.

Accounts Receivable

The "Accounts Receivable" problem consists of preparing bills to customers for goods or services rendered, and providing for other actions that may be needed such as second notices to slow payers, credits where too large an amount has been paid, etc.

A department store with many charge accounts will have an acute form of this problem. A utility that sells electricity, gas, or water may have the problem on a scale a hundred times larger. So will a municipality collecting taxes from all the residents of an area (though this will occur only once a year usually); and so will an insurance company sending periodic premium notices to all its policyholders.

This has been one of the large fields for application of punch card machinery. Automatic computers will have the following additional advantages: a large internal memory to contain tables of factors; ability to carry out voluminous instructions not only for usual cases but also for exceptional cases; and very high speed. Therefore we can expect that automatic computers will be applied and will be useful. Some large public utilities have been studying for some time the application of powerful automatic computers to this phase of their business.

Message Accounting and Telephone Companies

"Message Accounting" is a form of the accounts receivable problem for a telephone company. It consists of counting the local calls of each subscriber in message units, recording and pricing his long distance calls, and preparing monthly bills.

Bell Telephone Laboratories has developed automatic message accounting apparatus, and has tested it in Media, a suburb of Philadelphia. They anticipate that this equipment will prove to be successful, and will eventually be installed in modified or improved form all over the country, resulting in billing that is less expensive and more accurate.

Sales Analysis

Sales analysis (and market research) consists of analyzing sales of products to show comparisons of territories, products, salesmen, selling methods, buyer preferences, etc., so as to discover more profitable methods of selling and more profitable products to sell. Here the sky is the limit in methods which can be employed, data which can be collected, and information which perhaps can be deduced.

One market research firm has divided the country into scientifically selected sample areas and chosen certain sample families. Then it correlates the radio programs actually listened to, the radio advertised products to be found on bathroom and kitchen shelves, and radio sales efforts. The firm is then able to tell radio advertisers exactly what buying results occur as a result of what programs are listened to. One of the firm's main difficulties is delay in processing information; and it plans to use advanced automatic computing machinery to gain speed.

Accounting in General

Accounting in general consists of posting transactions to the proper ledger accounts, making trial balances, and providing financial statements. For many years companies have been using punch card machinery for this purpose, and the system may be so well worked out that the annual statement for a calendar year just passed may be available on January 2 of the next year. Depending on the number of accounting items to be handled, there may be some saving in moving the task from punch card machinery to automatic computing machinery.

Budgeting

Budgeting consists of estimating future monetary requirements for a department, a factory, an office, or some other production unit, so that future expenses can be planned for. Determining a budget of course consists of taking actual past expense figures, and then modifying them for a number of variables which the accountant believes will apply for the future period.

In simple cases this can be done with pencil, paper, and desk calculating machine. In complicated cases, there may be a great number of different production units to be budgeted, and many variables to be considered; and this will be a good problem for an automatic computer.

Operations Research

Operations research consists basically of the application of mathematics, military strategy, statistics, and other scientific methods to the evaluation of operations involving men and equipment in war, business, and other complex activities. A good part of it is common sense enriched with scientific knowledge and imagination. Much operations research can be carried out with pencil, paper, and a desk calculating machine, but there are problems involving so much calculation that access to automatic computing machinery is necessary.

Mathematical Programming

One of the subdivisions of operations research is *mathematical programming,* also called *linear programming.* This is a technique for solving a set of simultaneous equations where the variables are confined by certain limits. For example, the solution may have to meet the condition that the value of x is between 12 and 50. This kind of problem arises where "a group of limited resources must be shared among a number of competing demands, and all decisions are interwoven, because they all have to be made under the common set of fixed limits." A great many scheduling problems are of this kind, and finding the solution which is "best" under certain conditions is a problem in mathematical programming. Most such problems require extensive computing facilities to be solved.

Production Scheduling and Control

Production scheduling consists of arranging the production of a number of orders in a factory in such a way that the materials, labor, and machines are used as efficiently as possible and the desired timetable of goods produced is achieved. Of course, in practice, no sooner is a schedule made than it has to be broken because some predictions are not fulfilled and interruptions occur. Production control means control over the schedule in such a way that as changes come along, such as the spoiling of material, the receipt of rush orders, the breakdown of machines, etc., the schedule is corrected and brought up to date, and the production superintendent is able at all times to know where every order is and to take reasonable action to keep production going. Production scheduling and control will become easier and more efficient with the use of automatic computers.

Material Scheduling

Material scheduling, which is a part of production scheduling, consists of converting a production schedule calling for fulfillment of certain orders into a schedule showing which materials will be needed at what times so as to fulfill the orders. Basically, it is the result of multiplying the amount of each type of material needed for each unit of product by the number of units of product ordered; then corresponding types of materials are added (nuts and bolts of a given size, for example) for different products, to obtain totals. The whole is carried out with due regard to the time when needed, often expressed in weeks or days before expected completion of the order.

For the building of a ship, for example, the total number of different items may be 20,000 but usually only a small number of similar ships will be made at one time. For the construction of electric toasters, however, perhaps the total number of different items of material and subassemblies entering into their construction may be 100, but the number of electric toasters to be made in any week may be large.

Machine Loading

Machine loading is another part of production scheduling. It consists of arranging the work on machines in a factory so that each machine is properly occupied with the most useful work to be done on it, and the work produced by the machines will be sufficient for the production of the group of orders. Always of course, previous orders uncompleted and new orders being started have to be taken into consideration. The basic machine loading information is obtained by multiplying (1) the amount of machine time on each required kind of machine recorded as necessary in the drawings for the product by (2) the number of items of product called for in the production schedule; the next step consists of fitting the required machine time into the existing load on the machines in the factory. Of course, alternatives may have to be considered where production of a certain part can be done on any one of several machines.

Nearly always a reasonably good schedule that is sufficient is accepted. The best possible schedule would require both automatic computing machinery and the technique of mathematical programming.

Labor Projection

Labor projection is another part of production scheduling. Just like machine loading, it consists of determining the amount of each kind of labor required to produce the batch of product scheduled. Again the information is obtained by multiplying unit amounts of labor by the total number of items of product being made, and the whole calculation needs to be carried out with due regard to the days when the labor is needed.

Assembly Line Balancing

The balancing of an assembly line means arranging the work to be done on the line so that at different work stations an amount of work lasting the same time is called for. Some operations of course have to be completed before others, but many permit a choice as to when they may be done; it is these operations which are distributed in such a way that there will be no bottlenecks along the assembly line. A second part of the problem is rearrangement of the assembly line work so that for different production rates the assembly line will operate either faster or slower, but still with no bottlenecks.

This is the kind of problem which can be solved well by an automatic computer because its large memory can hold many instructions and conditions.

The Most Profitable Production Schedule

A big processing company may have several plants with different productive capacities, and it may be able to buy different grades of raw material subject to certain limitations on the amount available. It has the perennial problem: How to purchase raw materials and employ its capacities to produce what products in which quantities so as to obtain the maximum profit? ·For example, when crude oil is refined, different quantities of gasoline, fuel oil, etc., can be made.

The original data for solving the problem consists of: (1) forecasts from the sales department of what they think they can sell; (2) estimates from the purchasing department of what grades of raw material can be bought at what prices; (3) information from the production department of what ranges of final product the plant capacity can produce; etc. The technique to find the most profitable production schedule is mathematical or linear programming. Each additional variable considered multiplies the amount of calculation. This kind of problem is appropriate for a big computer.

Inventory Control

Inventory control will arise as a problem in almost any kind of large business, from a factory to a department store. The problem consists of knowing what stock is on hand, estimating future requirements, issuing reasonable orders to replenish stock taking into account the time needed to fill such orders, and posting stock received and stock issued.

Again the problem is simple on a small scale, and difficult and exasperating on a large scale. Certain types of automatic computing machinery have been designed expressly for inventory control. One such computer is in daily use to keep track of flight seats for an airline; several are in use in department stores for records of stock, such as furniture, having a high unit sales price.

Magazine Subscription Fulfillment

Magazine subscription fulfillment requires a system for maintaining the addresses and records according to which a magazine is mailed periodically to its active subscribers. For a weekly magazine with over 4 million subscribers, this is a gigantic problem; and for smaller magazines, the problem may still be very large.

A good deal of study and effort has gone into using modern automatic data processing machinery. A new machine in use for the purpose is a facsimile copier. It "looks" at a typed address on the subscriber's card, and copies it with dots on a continuous white paper tape that is subsequently cut and glued to copies of the magazine.

The applications of automatic computers and related automatic computing machinery in business are steadily increasing. The best teacher in how to use automatic computing machinery is continued, long-term experience. As a result of that experience, management will learn how to present to the machine more and more arduous questions that it will answer swiftly and correctly.

VII:5 MILITARY APPLICATIONS OF ANALOG COMPUTERS*

The military applications of computers are far more extensive and varied than are civilian applications. This is so for several reasons. To begin with, the military utilize practically all of the civilian data-processing devices for essentially the same purposes as do civilians. They also utilize some of them for purposes which are peculiar to their trade. Then, they have a large variety of computers which have no civilian counterpart. And finally, the number of computers is great because military necessity provides virtually unlimited funds.

Generally speaking, the military have been using computers systematically much longer than have civilians. This longer usage has of itself naturally led to a better appreciation of computers and to their wider application. Moreover, the military have special reasons of their own for using computers. For instance, the problems which they must solve are often very complicated, and yet solutions must be found rapidly, repeatedly, and with adequate accuracy. Only a machine, or men assisted by a machine, can meet the requirements. Also, only a machine can function under many conditions where computing is required. This may be so because of space or weight limitations, especially in airborne applications, or because of conditions intolerable to human beings, such as high accelerations or intense atomic radiations. Furthermore, a machine can be continuously alert for prolonged periods of time, and is not subject to psychological stresses. In short, mechanized computing can help men, can do a better job than men, or can operate where men cannot.

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* This discussion is necessarily limited by security considerations.

The systematic development of computing devices by the military dates from World War I.[1] It received greatly added impetus during World War II.[2] In this development, the vast majority of special purpose military computers have been and are analog. The early ones were predominantly mechanical, but more and more they tend towards the electronic.[3] As noted elsewhere in this book, most analog computers contain some digital features. However, basically digital computers for strictly military applications have been developed in the last few years only.

Almost anything that can be formulated for numerical or logical computation is apt to turn up in a military computer. Such devices can help, not only to direct guns, but also to solve logistic (supply) problems, and to enable a tactical commander to reach a quick decision in a complex situation.

Two problems have an especially important place in military computer applications. These are the *fire control* and the *ballistic* problems. They merit special consideration and will be outlined in the next several paragraphs. There are several versions of the fire control problem, and these have led to many varieties and a large number of computers.

The Fire Control Problem

A major activity of the Armed Services is launching missiles at targets. An aircraft may fire a rocket at another aircraft, or drop a bomb on a factory. A submarine may fire a torpedo at a ship, or a destroyer may project a depth charge at a submarine. Such cases are almost endless, and each presents an instance of the fire control problem. In every case there is motion of one or more bodies. The missile certainly moves from its launcher towards the target. The target may be in motion, and so may the launcher. All of these motions, when present, must be suitably taken into account if the missile is to have a reasonable probability of reaching the target. Another motion which can also affect the result must likewise be accounted for. This is the motion of the air mass, i.e., the wind. Still another set of motions can be involved. These are the roll, pitch, and yaw of the firing vehicle, which may affect the aiming of the launcher.

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[1] Navy Ordnance Activities — World War 1917-1918 / Government Printing Office / 1920, 266 pp & App.

[2] Rowland, B., and W. B. Boyd / U. S. Navy Bureau of Ordnance in World War II / Government Printing Office / 1953, 522 pp & App.

[3] Greenwood, I. A., J. V. Holdam, Jr., and D. MacRae, Jr. / "Electronic Instruments", Mass. Inst. of Technology Radiation Laboratory Series, vol. 21 / McGraw-Hill Book Co., New York / 1948, printed, 708 pp.

Proper accounting for all the many motions which may be present in a missile launching is a complicated problem. Its complexity is usually aggravated by a number of secondary problems which must be solved along with the principal problem. The speed and accuracy with which all these problems must be solved can be very high, largely due to the ever higher speeds of targets and firing vehicles.

A principal component of the fire control problem is the *tracking* problem. Primarily the tracking problem relates to the target. It may also relate to other things, as in the case of a guided missile, but we shall consider only the target. It is necessary to track the target to determine its motion so that we can launch the missile correctly. Although complete knowledge is not always necessary, we do need to know enough to insure that the missile will reach the target, or come close enough to be effective.

Tracking is usually done by optical or radar devices, or equivalent means. In optical tracking, telescopes pointed at the target can measure the horizontal and vertical angles which fix its direction. A rangefinder can fix its distance. The two angles and the distance together determine the position of the target with respect to our observing station. We can make a similar determination by using radar. When we have determined a number of successive positions of the target, we know what its present motion is. Then, assuming that the present motion will continue for a short time, we can predict where the target is going to be in the next several seconds. Using this prediction, we launch our missile to meet the target at one of its future positions. We direct our missile at a future position, of course, because the target will have moved on from where it was at the instant of launching. (A hunter calls this "leading the bird".)

The above procedure applies in principle when we drop a bomb on a factory. The factory does not move on the ground, of course, but to the bombardier it appears to move. This apparent motion of the target is due to the actual motion of the bomber, a minor case of relativity. The apparent motion is handled in essentially the same way as a real motion.[4]

The tracking information obtained by telescopes and rangefinder, or otherwise, becomes the input for a computer. The computer analyzes the information. Some computers are manually assisted and some are fully automatic. In either case, the analysis deduces the necessary elements of the target's motion and predicts where the target will be when the missile meets it. The computer may also have other inputs, as for the relevant motions of the firing vehicle and for the wind. Naturally, some computers are more elaborate than others, and some computer functions may be supplied externally to the main device.

The mechanization of the tracking problem is somewhat complex, but even more is required. For instance, missiles almost never travel in straight lines or at uniform speed. The curved path of a missile is called a trajectory. The curvature comes from a number of sources. One is the effect of gravity which is always deflecting the missile downward. Another source is the varying regions of wind. These tend to carry the missile along with them as it passes through. Still another cause of curvature is the side thrust of the air. This occurs when an elongated missile is not aligned with its direction of motion. Besides curving, a missile also changes speed along its trajectory. For example, a rocket increases speed till "burnout," when it starts losing speed because of air drag. There are even more matters which must be considered in a full mechanization of the fire control problem. However, enough has been said to suggest its complexity and some of the things with which a fire control computer must deal.

In obtaining its solutions, a fire control computer is aided by the circumstance that data as to the traget and other variables are usually fed in more or less continuously. Accordingly, it does not have to depend upon a single set of data, but can usually arrive at a running average of the input values. Moreover, computer outputs such as target's present direction can often be compared with observed values at frequent intervals. In this way there is a tendency to correct out any cumulative errors which may have developed.

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[4] Nielsen, K. L., and J. F. Heyda / The Mathematical Theory of Airborne Fire Control — NavOrd Report 1493 / Government Printing Office / 1951, 199 pp & App.

The Ballistic Problem

Fortunately for fire control designers, a considerable portion of their problem can, in effect, be predigested. This portion does not, then, have to be solved in the field. It is known as the ballistic problem and relates to missile trajectories. Incidentally, it was this problem which caused the "Ballistic Engine" to be invented.[5]

In the ballistic problem, the trajectories of missiles are worked out for various conditions. These conditions comprise the defining characteristics of the missile; the altitude, direction, and speed of launching; propulsion, if any (as for rockets); atmospheric conditions encountered, including wind; and so forth. Among the answers obtained are the position coordinates and the velocity components of the missile as functions of time. These answers are first obtained for assumed standard conditions. Then, the effects on the answers of variations from standard conditions are worked out. Finally, all of this information is suitably organized and made available for use in the field. In the field, it may appear in tables or graphic form for manual use. Alternatively, it may be built into a fire control computer. The solutions of the ballistic problem are themselves obtained by computer. In fact, this was one of the first applications of MIT I (p. 114) and of ENIAC.

The foregoing problem is strictly one of "exterior" ballistics. There is also the "interior" ballistic problem which treats of what goes on inside the gun or rocket. This problem is likewise a subject for computer application.

Flight and Navigation

The simplest auto-pilot must do a modicum of computing. When it is supplemented by a landing or navigation system, the amount of computing increases considerably. Loran and other radio navigation systems require computing both in the field and for preparation of special charts. Such systems and radar have tended to minimize the need for celestial navigation.

The flight control and guidance of missiles require extensive computing, both airborne and surface based. Airborne components of such systems must be kept to a minimum of weight and size. Their useful life (after check-out) may be brief, but ruggedness and reliability are musts. These requirements strain the capabilities of the best designers. Kindred computing systems are used in the fighter direction of combat air patrols and similar activities. In fact, as was suggested above, there is almost no limit to the use of mechanized computing in connection with military activities.

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[5] Wainwright, Lawrence / A Ballistic Engine / University of Chicago, Master's thesis, not published / 1923, 28 pp.

Training

Special purpose computers of various kinds are used by the military for training purposes. The well-known Link aircraft trainer with its auxiliaries is an example. Similar trainers are used for submarine and other specialized personnel. These devices utilize computers, mostly analog, which are so designed and operated that they very realistically simulate service or combat situations. By using them, the trainees can even be taught the correct responses to situations which, if actual, would be fatal unless correctly mastered.

A training computer for gunnery will present synthetic targets which an instructor can control as to character, aspect, range, motion, and so forth. The trainees operate their instruments and weapons just as in a combat situation and the computer scores their effectiveness. The realism of such a device can be heightened by using motion pictures and sound recordings made in actual or simulated combat.

VII:6 APPLICATIONS OF AUTOMATIC COMPUTING MACHINES IN OTHER FIELDS

In addition to the applications of automatic computing machinery in business and in military affairs, there are, of course, important applications in other fields: in government, engineering, science, and the exploration of ideas.

The Census

Of all the handling of information done in a government, the periodic census of any large country involves probably the greatest amount. The 1880 census of the United States using clerical methods alone took over seven years to complete, and was directly responsible for the invention of punch cards and punch card machines by Dr. Herman Hollerith. The prospective work of the 1950 census of the United States was in turn directly responsible for the first contract for a high-speed, high-capacity, commercial automatic digital computer, the first Univac. Such a machine possessing a considerable memory uses more efficiently the passage of punch cards (or magnetic tape) through input: selective totals can be simultaneously accumulated in over 500 registers.

Logistics

Logistics, in military usage and some other usages, refers to the planning and scheduling of manpower, training, supplies, and shipments so that a given military force will have what it needs month by month in order to accomplish a stated objective. At least one Univac has been used by the U. S. Air Force to perform this kind of data processing. Another automatic digital computer has been used by the U. S. Navy for the same purpose. And in other fields, such as the calculation of index numbers, governmental production of information may be materially aided by automatic computing facilities.

Prediction of Elections

In 1952 and again in 1954, automatic computers including a Univac were assigned on the evening of Election Day to the job of predicting for the television audience from the early returns the most likely outcome of United States elections. In fact, many people have seen automatic computers only on television on these occasions.

The predictions made by Univac for a radio broadcasting company on November 4, 1952, make an interesting story. During the preceding four weeks, the machine program was worked out, and finally accepted at the last minute, early in the evening of November 4. Then at 9:15 pm on Election Night, Univac calculated its first complete set of predictions. The automatic printer typed out the following: "Univac predicts, with 3,398,745 votes in, 93 electoral votes for Stevenson and 438 electoral votes for Eisenhower. . . ." The men around the machine could not bring themselves to believe this prediction, contrary as it was to many others. So they swiftly changed the "national trend factor" in the formula, which the machine had computed as "40 per cent shift to the Republicans" to

"4 per cent" and required the machine to recompute. About quarter of ten they released the tampered-with prediction. Later in the evening it became clear that the 40 per cent trend factor was much closer to the truth than the 4 per cent factor. About 10:30 pm a vice president of the manufacturer spoke on TV to explain and apologize for the discrepancy. After that the Univac predictions were announced unmodified. The final prediction run at 12:45 am, November 5, was 119 electoral votes for Stevenson and 412 electoral votes for Eisenhower. The actual result, known by the morning of Nov. 5, was 89 electoral votes for Stevenson and 442 electoral votes for Eisenhower. It seems evident that automatic computer commentary on elections will henceforth be a regular feature of election nights.

Economics

In economics many questions await powerful computing facilities combined with adequate economic information. The answer to a question like "If the price of steel goes up 10 per cent, how will farm prices be affected?" will then be able to be computed. Work in this direction has proceeded, developing what is referred to as the structure of the economy of a country. It requires the solution of upwards of 50 simultaneous equations in 50 unknowns.

Aircraft Design

We turn now to some of the applications of automatic computers in engineering.

The design of an aircraft requires a large number of calculations of stresses, strains, and other forces on each part of the structure. Although the mathematics of the physical situation is rather well understood, yet the only way of solving the intractable mathematical equations is through numerical measurements, calculations, and approximations.

This engineering problem has been solved with the use of automatic computers by many of the large aircraft companies. Some have even constructed their own computers. An example is the Boeing Electronic Analog Computer.

Other Engineering Design

Many other problems having to do with engineering design require a large amount of computation. The shapes of hundreds of individual blades in a turbo-jet engine vary from blade to blade according to their distance from the front of the engine; and these all have to be computed first and then produced. Other problems of engineering design requiring extensive computing are vibration and resonance problems, including flutter in aircraft, and oscillations in many other kinds of structures; the design of cams, either two-dimensional or three-dimensional; in an oil refinery, rapid analysis of mixtures of gases and liquids; the programmed control of machine tools; the distribution and stability of electrical power networks; the design of hydroelectric systems; etc.

Astronomy

In many fields of science, automatic computers have a considerable part to play and in some cases a completely essential part. One area where computation has always been a major problem is astronomy. For example, the problem of just recognizing a comet or minor planet or asteroid at later times depends on making several observations and establishing the orbit that the body is following. Automatic digital computing machinery has made possible some splended achievements in the field of computation of orbits; the IBM Electronic Sequence Controlled Calculator determined the position of the moon every six hours for 400 years, with an accuracy that was previously entirely unattainable. And automatic analog computers are responsible for keeping a telescope pointed at a heavenly body while the astronomer watches it through the eyepiece.

Nuclear Physics

In physics, extensive computation may be needed in many areas. In nuclear physics, for example, an investigation may be desired of the effects of a beam of neutrons on living tissue. The mathematical equations are far too difficult to be solved in a straightforward mathematical way. But the physical situation may be approximated to by the following process: consider a neutron emitted from the source; let it enter the tissue and collide at random with the nucleus of one of the chemical elements, nitrogen, calcium, carbon, . . ., present in the tissue; compute the damage to the tissue from this collision; and make this computation over and over again for a succession of neutrons, making random choices where necessary. This kind of process with random choices at suitable points can be done very deftly with an automatic computer; and the putting together of 10,000 samples of damage from individual neutrons to determine the whole effect can be done in a few hours on a swift automatic computer, whereas it would take years without such a machine.

Crystallography

In crystallography, a scientist may desire to know the arrangement of the various kinds of atoms in a crystal. He begins with a pattern on a photographic plate of the refractions made by a crystal of a beam of X rays directed at it. In the 1930's the measurement of the plate took three months, and the computations three years; but currently with automatic computing facilities the determination of the crystal structure may take a few hours.

Other areas in physics where automatic computers have application are the study of the behavior of shock waves and supersonic missiles: the study of behavior of beams, floors, and other structures under stresses and strains; the study of the phenomenon of cavitation—the formation of a cavity of froth and low pressure around the steering surfaces of a swift missile in the water; and more besides.

Chemistry

One of the largest problems of chemistry is not making new experiments with chemicals but knowing what is in the literature about past experiments. Here is a record of the number of abstracts published in "Chemical Abstracts," which started publication in 1907:

Year	Cumulative Number of Published Abstracts
1910	50,000
1920	200,000
1930	400,000
1940	820,000
1950	1,100,000
1953	1,600,000
1955	1,800,000 (est.)

It is evident that it is ceasing to be humanly possible for a chemist to survey the literature on any given subject. For this reason, an intense effort is being made to apply automatic data handling machinery to this problem.

Weather Forecasting

One of the problems to which a good deal of thought and study has been given is weather forecasting using a swift automatic computer. Some forecasts have been made using automatic computers. Currently, however, it seems that much more effort will have to go into both formulas and observations before successful forecasts can be made. Basically, the weather seems to be a very turbulent affair, like bubbles boiling in a pot containing many different liquids, or like a torrent of water splashing over an irregular moving belt.

Other Areas of Science

Automatic computing machinery has been applied or may be applied in many other areas of science. A technique requiring extensive computing is multiple factor analysis; it is used in the analysis of psychological traits, the question of what traits you have succeeded in measuring when you give a dozen tests to each of 100 persons. It has also been suggested that automatic computing machinery would be useful in the diagnosis of disease: a physician would present to a machine all the symptoms and evidence which he was able to observe in a person; and the machine would report for consideration the most likely possibilities for disease. An automatic machine for electronically "recognizing" slides showing normal and cancerous tissues is under development.

Statistics

In statistics, automatic computing machinery is useful, among other ways, in the production of a series of random digits – a series of digits in which at each successive place each digit from 0 to 9 has an equal chance of being selected. Now it is not nearly so easy to construct a random series of digits as might be supposed. If you or I were setting out to do this, we would probably try to avoid sequences of the same digit; and this would tend to make the series too evenly distributed and less random than it should be. Also, if we set out to make a series of 500 random digits, we would probably try to arrange exactly 50 zeros, 50 ones, 50 twos, and so forth, here and there through the series. But this again would be too even a distribution to be random.

Random distributions can be produced by an automatic computer in two ways. One is the completely random way, unable to be repeated, as for example by amplifying the random distribution of electronic background noise in an electronic tube and using that to cause the selection of a digit. The other way is the "pseudorandom" way, using a mathematical process which is repeatable, but in which the digits produced have apparently all the statistical properties of random digits.

Using a series of random digits, and statistical operations upon them, an automatic computer may be used to determine properties of theoretical frequency distributions of mathematical statistics. This is especially useful where the mathematical definition is too difficult to be handled in a straightforward mathematical way.

Mathematics

In some questions of pure mathematics, in particular the theory of numbers, automatic computers have been used. In this way, certain very large numbers have been proved to be prime; that is, such a number has no factors other than itself and one. Also, the mathematical constants π and e have been calculated to more than 2000 decimal places by the use of automatic computers.

Language Translation

Translating from one language to another has been accomplished by automatic computer. The first successful trial occurred in 1954 when an IBM Type 701 translated from Russian to English.

A total vacabulary consisting of 250 Russian words (in latinized spelling) relating to the fields of politics, law, mathematics, chemistry, metallurgy, communications, and military affairs was punched on punch cards. Associated with each Russian word and punched on the same card were one or two English equivalent words, and three codes designated 1st, 2nd, and 3rd. These codes (linguistically they can be considered "diacrictical marks") together with the program and six "rules of operational syntax" caused appropriate translation. For example, different meanings of words could be selected; the order of words could be left unchanged or altered; a word could be treated as a whole or could be divided into a root and a suffix. The dictionary stored in the machine was equivalent to 6000 machine words of 36 binary digits each, and the program consisted of about 2400 program steps. With about 5 to 8 seconds for each translation of each sentence, the machine produced translations such as the following:

KACHYESTVO UGLYA OPRYEDYELYAYETSYA KALORYIYNOSTJYU
The quality of coal is determined by calorie content.

MI PYERYEDAYEM MI SLYI POSRYEDSTVOM RYECHYI

We transmit thoughts by means of speech.

There is a long way to go still, of course, but the possibility of effective linguistic translation by automatic computers has been definitely demonstrated.

Logic

Machines have been used to calculate the truth value of complicated combinations of propositions and to explore the relations of statements. This promises interesting applications in the future, when an automatic computer can be programmed to deal with meanings. Then for example a computer may perhaps take a section of law, master it, and point out loopholes and contradictions. Certain sections of symbolic logic have already been opened to the application of computers.

Games and Behavior

Many types of games have been played on and with automatic computers. They include nim, tit-tat-toe, billiards, checkers, and chess. Computers have also been programmed to "learn from experience"; to solve simple labyrinths and remember them. It is evident that no intellectual barrier exists for automatic computers to play games and play them well; but there are so far definite barriers in capacity. The memory of a computer is one-dimensional so far rather than many-dimensional or associational like the memories of human beings; and so the problem of a computer's quick access to many different aspects of information may not be solved for a long time. For many years, the best chess player will remain a human being.

Thinking

Finally, the powers of automatic computers have been carefully considered in the exploration of the nature of thinking. Is there any kind of thinking that a machine cannot do?

One criterion of thinking, proposed by the English mathematician Turing, is that a machine and a human being in different rooms should carry on a conversation using teletype, and if at the end of a half hour or so, the human being could not tell if he were conversing with a machine or another human being, then the machine would qualify as thinking. A training course in the programming of an automatic computer given at the University of Michigan includes the following term problem for students: "Devise a program which will make the automatic computer perform what appears to be a reasonably lucid conversation about one particular subject (for example, the weather.)" No one has yet argued that it would be impossible for the computer to carry out this problem, although there is a division between computer men who hold that machines can think, and those who hold that machines cannot think. The crux of the argument depends of course on the meaning of "thinking." The word can be defined in different ways according to the position of the disputant. Actually, included under the term thinking, there is a long list of reasonable operations with information. Some of these a machine can perform well, and others no automatic computer has yet performed at all. It would be rash indeed, however, to assert for the limitless future that "a machine cannot think."

VII:7 RECOGNIZING AREAS WHERE AUTOMATIC COMPUTING MACHINES MAY APPLY

A logical and pointed question which a management engineer, methods engineer, or systems analyst can ask is this: How can I recognize an area where automatic computing machinery may usefully apply? What are the factors for determining it? Briefly, the main factors are these:

1–the amount of information being processed;

2–separation from operations that have not yet been successfully mechanized;

3–the amount of gain from more automatic processing of information;

4–resemblance to other applications that have been successfully mechanized.

Each of these factors will now be explained.

The Amount of Information Being Processed

The first factor in determining whether an organization is likely to be able to use automatic computing machinery is the amount of information being handled in the organization. If a great deal of information is being processed, the fact is at once evident. Many people are sitting at desks, using pencils, paper, forms, rubber stamps, rule books, files, etc. Small desk machines that handle figures, such as adding, bookkeeping, and multiplying machines, will here and there be apparent. In fact, punch card machines, the advance guard of more automatic computing machinery, are likely to be in evidence. In short, if there is a large volume of clerical work, especially of the repetitive kind, then there is a good chance for applications of automatic computing machinery.

Engineering work will also have some applications for automatic computing machinery, if it is accompanied by groups of clerks with desk calculators. But all engineering work together probably amounts to less than two per cent of all processing of information. In fact, engineers in some industries, such as the construction industry, find that reference tables and slide rules used occasionally are sufficient for them to turn out all the calculations they need. This is true, curiously enough, in spite of the fact that it was the engineer's side of the problem of processing information, as exemplified by a professor at Harvard University (Professor Howard H. Aiken) and a physicist at the Moore School of Electrical Engineering (Dr. John W. Mauchly), which was mainly responsible for the renewed emphasis on automatic digital computing machinery more than 120 years after Charles Babbage in England conceived the idea behind it.

Besides volume, there is another basic difference between clerical work and engineering work. For clerical work, the number of operations per item of input information is relatively small, perhaps three to a dozen operations. But in much engineering work, each item of input information may require 50 to 500 operations and even more. This difference affects the kind of automatic computing machinery which may apply.

To sum up the first factor, if a lot of information is being processed, the chance is good that automatic computing machinery will apply; if very little information is being handled, the chance is remote.

Separation from Operations that Have Not Yet Been Successfully Mechanized

In considering the application of automatic machinery to a process, it is necessary to determine whether operations not yet successfully handled by any machine can be separated from the process.

For example, there is no machine yet which will "look" at handwriting, and punch characters that exactly correspond with it. Nor is there a machine which will first orient a piece of paper, then "read" typewritten letters in a certain spot on the paper, and punch characters to agree. Nor is there a machine which will listen to words, recognize their sounds, and punch characters to correspond with their proper form as spelled. All these operations, and more besides, are operations upon information which no machine can yet perform.

Because of these so-far-unmechanized operations, there are some serious limitations affecting the application of automatic machinery for processing information. For example, whatever information is given to a machine must usually be prepared by a human being and expressed in language acceptable to the machine; and this is true not only for problem data but also for instructions. This limitation is, however, being reduced in importance, because instruments that measure a physical quantity are being equipped with added devices for expressing the measurement in a form that constitutes machine language for an automatic data processor. For example, in the testing of airplane models in wind tunnels, the readings of strain gages may be converted mechanically from measurements into punch cards. Even a beginning to operations of looking, reading, and recognizing has been made: a machine is now being designed that can look at and read figures on American Express checks, so that they can be sorted automatically instead of by hand.

The Possible Gain from Automatic Processing

In determining a possible area for application of automatic computing machinery, a third factor is a careful appraisal of the relative costs and advantages of the present system and the proposed, more automatic system.

It is not always true that the more automatic system is faster or cheaper. For example, there was once a section of a large paper company which had the duty of putting together weekly reports of products produced by different plants. One report required the assembly of information on 500 products from 30 plants. The section when interviewed had recently given up an installation of punch card machines that required 15 people as well as the machines; it was using a manual system of pegboards and peg strips that used 9 people and produced the reports faster!

But for every instance like this one, there are dozens where automatic computing machinery can be applied well. Indications in favor of a more automatic system include the following:

1–machine language to be put into the computer can be obtained as a byproduct of some other operation;

2–four or more operations are performed on the average for each item of input information;

3–results are wanted much faster than available at present so that they can be considered in time to be useful in making decisions.

Resemblance to Other Applications that Have Been Successfully Mechanized

Finally, from a practical viewpoint, it is much easier to make a successful application of a new device in an area where other companies have shown by example that it can be done. A previous successful example changes the mental environment in which adoption of a new method takes place; and it reduces the amount of work needed to change people's minds. Therefore, a good way to see possible applications of automatic computing machinery is to know of many applications that have been made.

It is a notable point that the investment in machinery for each worker in a factory is reported to range from about $3000 to about $20,000 (in the chemical industry); the average is perhaps somewhere around $9000. But, the average investment in machinery for each office worker is reported to be less than $1000; and this is another indication of the great room for expansion that lies in the field of automatic machinery for handling information.

SECTION VIII

MISCELLANEOUS

VIII:1 REFERENCES: BOOKS AND OTHER SOURCES OF INFORMATION

Presented here is a listing of the various sources of information about all aspects of automatic computing machinery. These sources fall into six main categories: periodicals; other collections of articles and papers published together; technical organizations which issue information; books; some outstanding articles and reports; and bibliographies other than this one.

Conceivably it would now be possible to compile a bibliography of many thousands of titles in the field of automatic computing machinery. But this is not easy to do, nor is it perhaps very worthwhile, when information is gushing forth as fast as it is now, and what was a good reference article in one year is superseded by a better article in the next.

As mentioned before, the punctuation sign "/", called the slant or virgule, is used as a separator between different items in a list, in the same way as in a table a vertical rule between columns separates between the different items in the row. The slant is particularly useful for achieving the effect of tabulating information without using large and clumsy tables. It suggests the vertical rule, yet does not have the misleading connotation of signs like the semicolon, colon, period, or dash – all of them presently having many meanings and overworked.

Periodicals

Following is a list of periodicals having some relation to the field of automatic computing machinery and information-processing equipment. The general plan of each of these entries is: name of of the magazine / publisher and address / frequency / a few comments.

American Business / Dartnell Publications, Inc., 200 East Illinois St., Chicago, Ill. / monthly, printed

Occasional articles on applications to business of electronic machinery for handling information.

Automatic Control / Reinhold Publishing Co., 430 Park Ave., New York 22, N.Y. / monthly, printed

One or two articles out of 6 or 7 per issue, on some aspect of computing machinery.

Automation / Penton Publishing Co., Penton Bldg., Cleveland 13, Ohio / monthly, printed

One or two articles out of about 15 per issue, on some aspect of computing machinery.

Business Week / McGraw Hill Publishing Co., Inc., 330 West 42 St., New York 36, N.Y. / weekly, printed

Occasional articles and reports on new developments and applications of data-processing machinery to business and industry.

Computers and Automation / Berkeley Enterprises, Inc., 36 West 11 St., New York 11, N.Y. / monthly, photo-offset

Articles, papers, and reference information on automatic computing machinery, and its implications and applications, including automation. The reference information includes:

- Roster of Organizations in the Computer Field
- Roster of Automatic Computing Services
- List of Automatic Computers
- Automatic Computing Machinery—List of Types
- Glossary
- Patents

"Computers and Automation" is the source of a good deal of the information contained in this book; it is the publication where that information is brought up to date from time to time.

Control Engineering / McGraw Hill Publishing Co., 330 West 42 St., New York 36, N.Y. / monthly

One or two articles out of seven or eight per issue, on some aspect of computing machinery.

Digital Computer Newsletter / Office of Naval Research, U. S. Navy Dept., Washington 25, D. C. / quarterly, photo-offset (reprinted in "Journal of the Association for Computing Machinery", which see)

News of automatic digital computers, other automatic digital data-processing machinery, and the organizations making them.

Journal of Accountancy / American Institute of Accountants, 270 Madison Ave., New York 16, N.Y. / monthly, printed

Occasional articles on electronic computers and their applications in accounting.

Instruments and Automation / Instruments Publishing Co., 845 Ridge Ave., Pittsburgh 1, Pa. / monthly, printed

Occasional articles on computer aspects of instrumentation.

ISA Journal / Instrument Society of America / 1319 Allegheny Ave., Pittsburgh 33, Pa. / monthly, $5 a year

Occasional papers on types of automatic computing machinery useful in instrumentation problems.

Journal of the Association for Computing Machinery / Association for Computing Machinery, 2 East 63 St., New York 21, N.Y. / quarterly, photo-offset

Technical papers related to programming, applications, construction, and other aspects of automatic computing machinery; reports and news of interest to computer people. This journal reprints the "Digital Computer Newsletter" (which see).

Mathematical Tables and Other Aids to Computation / National Research Council, Washington 25, D.C. / quarterly, $5 a year

Papers on properties of specific automatic computers; uses of computers in mathematical problems; news; etc.

MT, Mechanical Translation / Mass. Inst. of Technology, Dept. of Modern Languages, Cambridge 39, Mass. / irregularly published, 10 to 15 pages an issue, photo-offset

Bibliographies and abstracts of information on the translation of languages with the aid of machines; discussion; news.

Office Management and Equipment / Andrew Geyer, Inc., 212 Fifth Ave., New York 10, N.Y. / monthly

Frequent articles on the automatic office, automatic accounting machines, etc.

Proceedings of the Institute of Radio Engineers / Institute of Radio Engineers, One East 79 St., New York 21, N.Y. / monthly, printed

Occasional papers on electronic computers, although most of those submitted will be routed for publication to the "Transactions of the IRE Professional Group on Electronic Computers" (which see). The October 1953 issue was a special issue devoted entirely to computers.

The Programmer / Remington Rand, Inc., Electronic Computer Dept., 315 Fourth Ave., New York 10, N.Y. / bimonthly, printed, about 4 pages an issue

Brief articles on programming.

Transactions of the Institute of Radio Engineers' Professional Group on Electronic Computers / Institute of Radio Engineers, One East 79 St., New York 21, N.Y. / quarterly, printed

Technical papers related to the electronic construction of computers; and reviews of articles, papers, and books.

Proceedings

Besides the variety of information on many subdivisions of computers to be found in periodicals, other diverse collections of papers and talks given at meetings, symposiums, conventions, etc., have been published. Following are some of the more important recent publications of this type. The general plan of each entry is: issuing organization / title / publisher and address / year, mode of publication, number of pages / a few comments.

Association for Computing Machinery / Proceedings of the Association for Computing Machinery, Meeting at Pittsburgh, Pa., May 1952 / Association for Computing Machinery, 2 East 63 St., New York 21, N.Y. / 1952, photo-offset, 305 pp

Transcripts of 50 papers by many authors on history of computing machinery, descriptions of individual computers, logical design, programming, circuitry, magnetic memory, etc.

Association for Computing Machinery / Proceedings of the Association for Computing Machinery, Meeting at Toronto, Ont., Sept. 1952 / Association for Computing Machinery, 2 East 63 St., New York 21, N.Y. / 1953, photo-offset, 160 pp

Transcripts of 35 papers by many authors on numerical analysis, logical design, programming, and many other subjects.

Institute of Radio Engineers / Convention Record of the IRE, 1953 National Convention, Part 7, Electronic Computers / Institute of Radio Engineers, One East 79 St., New York 21, N.Y. / 1953, photo-offset, 71 pp

Transcripts of 15 papers, on electronic computers, diagnostic programs, and marginal checking.

Institute of Radio Engineers / Proceedings of the IRE, October 1953, vol. 41, no. 10, "Computer Issue" / Institute of Radio Engineers, One East 79 St., New York 21, N.Y. / 1953, printed, 350 pp (excl advtg)

Contains 41 articles and papers on diverse computer subjects, most of them technical, some of them nontechnical.

Institute of Radio Engineers / Convention Record of the IRE, 1954 National Convention: Part 4, Electronic Computers and Information Theory / Institute of Radio Engineers, Inc., One East 79 St., New York 21, N.Y. / 1954, photo-offset, 144 pp

Transcript of 25 papers on: application of information theory to communication systems; coding and noise; speed of computation; computer design and techniques; computer components.

Joint Computer Conference / "Review of Electronic Digital Computers" — Proceedings of the Joint Computer Conference, Philadelphia, Pa., Dec. 10-12, 1951 / Joint Computer Conference, c/o Association for Computing Machinery, 2 East 63 St., New York 21, N.Y. / 1952, printed, 114 pp

Transcripts of papers.

Joint Computer Conference / "Review of Input and Output Equipment Used in Computing Systems", Proceedings of the Joint Computer Conference, New York, N.Y., Dec. 10-12, 1952 / 1953, printed, 142 pp

Transcripts of papers.

Joint Computer Conference / "The Proceedings of the Western Computer Conference", Los Angeles, Calif. Feb. 4-8, 1953 / Joint Computer Conference, c/o Assoc'n for Computing Machinery, 2 East 63 St., New York 21, N.Y. / 1953, printed, 231 pp

Transcripts of papers.

Joint Computer Conference / "Information Processing Systems — Reliability and Requirements", Proceedings of the Eastern Joint Computer Conference, Washington, D.C., Dec. 8-10, 1953 / Joint Computer Conference,

c/o Association for Computing Machinery, 2 East 63 St., New York 21, N.Y. / 1954, printed, 125 pp

Transcripts of papers.

Joint Computer Conference / "Trends in Computers: Automatic Control and Data Processing", Proceedings of the Western Computer Conference and Exhibit, Los Angeles, Calif., Feb. 11-12, 1954 / Joint Computer Conference, c/o Association for Computing Machinery, 2 East 63 St., New York 21, N.Y. / 1954, printed

Transcripts of papers.

Office of Naval Research, Navy Mathematical Computing Advisory Panel, editor, and others / A Symposium on Commercially Available General-Purpose Electronic Digital Computers of Moderate Price / U.S. Dept. of Commerce, Office of Technical Services, Washington 25, D.C. 1952, photo-offset, 41 pp

Contains six papers and one abstract on computers of Jacobs Instrument Co., Monroe Calculating Machine Co., Computer Research Corp., Hogan Labs., Electronic Computer Corp., Consolidated Engineering Corp., and Physical Research Laboratories (now Marchant Research, Inc.).

Scientific American / "Automatic Control", issue of "Scientific American" for September 1952 / Scientific American, Inc., 2 West 45 St., New York 36, N.Y. / September 1952, printed, 196 pp

Contains eight well-written articles, some of them particularly interesting and informative, including "An Automatic Chemical Plant" by Eugene Ayres, "An Automatic Machine Tool" by William Pease, and "Information" by Gilbert W. King.

Organizations

Another important source of information about automatic computing machinery consists of organizations in the field. Some of them publish a good deal of information — particularly government and university laboratories, on investigations which they carry out, and manufacturers, on machines and other products which they make.

Among the laboratories which publish a large amount of information are:

Bell Telephone Laboratories, Murray Hill, N.J.
Franklin Institute Laboratories for Research and Development, Philadelphia 3, Pa.
Harvard University, Harvard Computation Laboratory, Cambridge 38, Mass.
Mass. Inst. of Technology, Digital Computer Laboratory, 211 Mass. Ave., Cambridge 39, Mass.
Moore School of Electrical Engineering, Univ. of Pennsylvania, Philadelphia, Pa.
National Bureau of Standards, Division of the National Applied Mathe-

matics Laboratories, and also Machine Development Laboratory, Washington 25, D.C.

U. S. Army, Ballistic Research Laboratories, Aberdeen Proving Ground, Aberdeen, Md.

For some of these laboratories, all that they publish will have a considerable bearing on automatic computing machinery; but for others, only a small part of a large output of publications will relate to computers. An inquiry addressed to any one of these laboratories should result in information as to what are their current publications about computers and where they may be consulted.

A good deal of the information published by manufacturers is of course advertising literature, and not very substantial; either it is poorly written or it is written with a definite bias. But some of the information which they publish consists of manuals of instruction for the operation of their machines, or descriptions of applications of automatic computing machinery; and such information may be substantial and useful. To obtain the publications of manufacturers is not always easy. What they publish is not usually in libraries, since its purpose is to be given out free to prospective or actual users, but not to other persons. Also the information changes rather quickly; editions of one year will be superseded by newer editions issued in the following year. Furthermore, very few large manufacturing organizations maintain a list or bibliography of their current publications; if such did exist, it would be a valuable aid for finding out what publications should be examined.

In spite of these difficulties there are ways of obtaining the information. One way is to go to exhibits of these companies and gather up literature there offered. Another way is to visit one of their offices in a larger city, and request whatever literature and information is available there. A third way is to write the head office (address below) and ask for specific literature, giving reasons why it is desired; regularly, there is no charge for such literature, and a manufacturer will usually give it out even to a person who is not a customer if he is convinced of a good reason for so doing.

Among the manufacturers which publish a quantity of information are the following:

Burroughs Corporation, Detroit 2, Mich., and Burroughs Research Center, Paoli, Pa.

Electro Data Corporation, subsidiary of Consolidated Engineering Co., Pasadena, Calif.

Ferranti Electric Co., 30 Rockefeller Plaza, New York, N.Y.
International Business Machines Corp., 590 Madison Ave., New York 22, N.Y.
Monrobot Laboratories, Monroe Calculating Machine Co., Morris Plains, N.J.
George A. Philbrick Researches, Inc., 230 Congress St., Boston, Mass.
Reeves Instrument Co., 215 East 91 St., New York, N.Y.
Remington Rand, Inc., 315 Fourth Ave., New York 10, N.Y.

Books

There are still rather few books in the field of automatic computing machinery. Most of them are in the following list. The general plan of each entry is: author / title / publisher and address / year, mode of publication, no. of pages / a few comments.

Aiken, Howard H., and others / Description of a Magnetic Drum Calculator / Harvard University Press, Cambridge 38, Mass. / 1952, photo-offset, 318 pp

This magnetic drum calculator is the Harvard Mark III computer, which was delivered to the Naval Proving Ground, Dahlgren, Va., in March 1950, and which commenced operating in 1951. The drums store 4200 quantities of 16 decimal digits each; the calculator adds in 5 milliseconds and multiplies in 13. This book is a fairly complete description of the detailed construction of an electronic computer.

Ashby, W. Ross / Design for a Brain / John Wiley and Sons, 440 4th Ave., New York 16, N.Y. / 1952, printed, 260 pp

An important book, and lucid even if not easy; full of examples. Discusses basically how a machine equipped with a great many on-off circuit elements that have at first mostly random connections can program itself for survival. The author is the inventor of the Homeostat and the Director of Research at Barnwood House, Gloucester, England.

Berkeley, Edmund C. / Giant Brains or Machines that Think / John Wiley and Sons, 440 Fourth Ave., New York 16, N.Y., 1949, 277 pp

This book is a carefully written introduction to automatic computers and their applications and implications. It contains a bibliography of over 350 references.

Booth, Andrew D., and Kathleen H. V. Booth / Automatic Digital Calculators / Butterworths Scientific Publications, London, England / 1953, printed, 231 pp

A valuable and interesting book by the heads of the Electronic Computation Laboratory of Birkbeck College, University of London, who have made a number of all-purpose electronic computers such as APEXC. The middle chapters of the book give plentiful details on how to construct an automatic electronic computer. The last chapter, "Some Applications of Computing Machines", discusses: x-ray crystal structure analysis; mechanical translation; games; and machine learning and intelligence.

Bowden, B. V., editor, and others / Faster than Thought — A Symposium on Digital Computing Machines / Sir Isaac Pitman & Sons, Ltd., London, England / 1953, printed, 416 pp

An interesting, informative, well organized, and well-written book, written by 24 contributors including Dr. B. V. Bowden. The three parts of the book are: The History and Theory of Computing Machines; Electronic Computing Machines in Britain and America; Applications of Electronic Computing Machines. The last part includes discussion of their use in crystallography, meteorology, astronomy, economics, chess, etc.

Diebold, John / Automation, the Advent of the Automatic Factory / D. Van Nostrand Co., 250 4th Ave., New York 10, N.Y. / 1952, printed, 181 pp

Discusses many ideas and contains a lot of information. Not technical. The book is an outgrowth of a report "Making the Automatic Factory a Reality" by a research group of students at the Harvard Business School.

Edison, Julian E., Lester S. Morse, Richard A. Pisitz, and George Sternlieb / Electronics — New Horizon in Retailing: The Application of Electronics and Electro-Mechanical Systems to Retail Control / AER Associlates, 6450 Cecil Ave., Clayton 5, Mo. / 1953, photo-offset, 94 pp

A thoughtful, interesting, complete, and well-documented "research report prepared by a group of students at the Harvard Graduate School of Business Administration, in partial fulfillment of the requirements of the course in retail distribution". Describes retail store information-handling needs and present and proposed systems for meeting those needs, including late developments. Discusses recent advances in the punched card and electronic fields, the attitude of retailers towards research, etc.

Engineering Research Associates, Inc., W. W. Stifler, editor, and others / High-Speed Computing Devices / McGraw Hill Book Co., 330 West 42 St., New York 36, N.Y. / 1950, printed

An extensive exposition of digital computing methods, machines, and devices. Some sketches. Extensive bibliography. Includes a chapter on analog systems.

Greenwood, I. A., J. V. Holdam, Jr., and D. MacRae, Jr. / "Electronic Instruments", Mass. Inst. of Technology Radiation Laboratory Series, vol. 21 / McGraw Hill Book Co., 330 West 42 St., New York 36, N.Y. / 1948, printed, 708 pp

In spite of the title, the book does not deal with oscilloscopes, voltmeters, etc., but with electronic computing instruments. It is a very extensive treatment of mechanized computing with emphasis on electronic methods for radar applications. An excellent treatise profusely illustrated. No bibliography as such, but numerous references in footnotes. Other volumes of this series should be consulted, especially vol. 19, "Waveforms".

Hartree, D. R. / Calculating Instruments and Machines / University of Illinois Press, Urbana, Ill., / 1949, printed, 134 pp

A clear explanation of a sampling of analog and digital machines and

their applications. Illustrated with sketches and photographs. Limited bibliography.

Korn, G. A., and T. M. / Electronic Analog Computers / McGraw Hill Book Co., 330 West 42 St., New York 36, N.Y. / 1953, printed, 372 pp

Theory and practical operation of DC analog computers with emphasis on scale factor considerations. Amply illustrated. Bibliography.

Murray, Francis J. / "The Theory of Mathematical Machines" / King's Crown Press, 2960 Broadway, New York 27, N.Y. / 1947, photo-offset, 116 pp

An extensive exposition of the elements and applications of mechanical, electrical, and electronic means of mechanized computing. Illustrated by sketches.

Office of Naval Research / A Survey of Automatic Digital Computers, Report 111293 / U. S. Department of Commerce, Office of Technical Services, Washington 25, D.C. / 1953, photo-offset, 109 pp

An important report giving full, comparable, technical details on 98 automatic computers, based on information collected generally in February, 1953.

Svoboda, Antonin / "Computing Mechanisms and Linkages", Mass. Inst. of Technology, Radiation Laboratory Series, vol. 27 / McGraw Hill Book Co., 330 West 42 St., New York 36, N.Y. / 1948, 299 pp

Largely a theoretical presentation of the applications of linkages to mechanized computing.

Van Foerster, Heinz, editor, and others / Cybernetics — Transactions of the 8th Conference, March 15-16, 1951, New York, N.Y. / Josiah Macy, Jr., Foundation, 565 Park Ave., New York 21, N.Y. / 1952, printed, 240 pp

Contains six papers on communication, cybernetics, etc., by Alex Bavelas, Ivor A. Richards, L. S. Kubie, H. G. Birch, Claude A. Shannon, D. M. McKay, and discussion by 16 other participants in the conference.

Wiener, Norbert / Cybernetics, or Control and Communication in the Animal and the Machine / John Wiley and Sons, 440 4th Ave., New York 16, N.Y. / 1949, printed, 194 pp

The book which revived the use of the term cybernetics, and established its modern meaning. Discusses the structure of the brain and nervous system, their parallels with the behavior of machines able to compute and control, and the implications of these ideas.

Wilkes, Maurice V., David J. Wheeler, and Stanley Gill / The Preparation of Programs for an Electronic Digital Computer / Addison Wesley Press, Inc., 238 Main St., Cambridge 39, Mass. / 1951

A description of the Edsac at the University Mathematical Laboratory, Cambridge, England, and of the programming techniques and library of programs developed for it.

Articles and Reports

A very large number of articles and reports exist in the automatic computing machinery field. The following list is a small selection, including those which have some particularly useful connection with ideas discussed in this book.

Akins, G. F. / "Principles of Automatic Control", Parts I, II and III in "ISA Journal", vol. 1, no. 1-3, Jan-Mar. 1954 / Instrument Society of America, 1319 Allegheny Ave., Pittsburgh 33, Pa. / 1954, printed

A very good account, with an excellent example, of the reasons for automatic control, the design of an automatic controller, and the application of an automatic controller to a process. These papers constitute the complete text of the material used in a training film.

Andlinger, Gerhard R., and others / "The Relation of Computers to Operations Research", Chapter 8, in "Operations Research: Challenge to Modern Management" / O. R. Associates, Box 245, Cambridge 38, Mass., / 1954, photo-offset, 120 pp

This chapter discusses the need for computers in operations research, the types of computers available, and some examples of their use to solve problems in operations research.

Association for Computing Machinery, Committee on Nomenclature, Grace M. Hopper, Chairman, and others / First Glossary of Programming Terminology / Association for Computing Machinery, 2 East 63 St., New York 21, N.Y. / 1954, photo-offset, 25 pp

Contains definitions of over 300 terms used in programming automatic computing machines. The committee included representatives of half a dozen different centers of computation.

Baxendall, D. / "Mathematical Instruments" in "Encyclopedia Britannica", 14th edition, vol. 15, pp 69-71

Two plates containing photographs of 12 instruments. Short bibliography. Mentions algebraic equation solvers; describes several instruments including planimeters, integrators, integraphs, harmonic analyzers, harmonic synthesizers.

Berkeley, Edmund C., and Robert A. Jensen / Constructing Electric Brains / Edmund C. Berkeley and Associates, 36 West 11 St., New York 11, N.Y. / March 1952, photo-offset, reprinted from 13 issues of "Radio Electronics"

Description of relay and electronic automatic computers and how they may be constructed, including many circuits; emphasis on small machines and the miniature automatic computer Simon as an example.

Berkeley, Edmund C., and Robert A. Jensen / Construction Plans for Simon / Edmund C. Berkeley and Associates, 36 West 11 St., New York 11, N.Y. / March 1952, photo-offset, 35 pp

Complete plans, circuits, essential wiring diagrams, parts list, etc., for "Simon", a miniature relay mechanical brain for educational purposes. It handles numbers up to 255, and performs nine logical and mathematical operations. From these plans a second Simon in California, a third one in Kansas, and perhaps others have been constructed.

Caldwell, Samuel H., and Vannevar Bush / "A New Type of Differential Analyzer" in "Journal of the Franklin Institute", vol. 240, no. 4 /

Franklin Inst., Philadelphia, Pa. / Oct. 1945, printed, pp 255-326

An extensive general description of the second Mass. Inst. of Technology differential analyzer, from the functional, operational, and engineering viewpoints. Well illustrated by diagrams and photographs.

Clippinger, R. F., Bernard Dimsdale, and J. H. Levin / "Automatic Digital Computers in Industrial Research", Parts I, II, III and IV / Raytheon Manufacturing Co., Waltham, Mass. / 1954, dittoed, approx. 90 pp

Examine many factors in handling large scale problems through the use of an automatic digital computer, and the costs and problems in establishing and operating a computing installation. A thorough and practical discussion.

Higgins, John A., and Joseph S. Glickauf / "Electronics Down to Earth" in "Harvard Business Review", March-April, 1954, pp 97-104 / Harvard Business Review, Soldier's Field, Boston 63, Mass. / 1954, printed

An appraisal of electronic computing equipment, covering operating characteristics, potential uses, misconceptions, and future trends.

Institute of Radio Engineers, Standards Committee, Electronic Computers Committee, Subcommittee on Definitions of Electronic Computer Terms, Robert Serrell, Chairman / Standards on Electronic Computers: Definitions of Terms, 1950 / Institute of Radio Engineers, One East 79 St., New York 21, N.Y. / March 1951, printed, reprint from the "Proceedings of the I.R.E." for March 1951, 8 pp

Contains definitions of about 130 words and phrases.

Newsweek Club and Educational Bureaus / "Robot Machines and Men: Is a New Age in the Making?" constituting the October 1953 issue of "Platform" / Newsweek, 152 West 42 St., New York 36, N.Y. / 1953, photo-offset, 23 pp

An excellent and complete presentation of the arguments on several sides of the topics: "How do robot devices work? The shape of the future. Some practical barriers. What role for human beings?"

Osborn, Roddy F. / "GE and Univac: Harnessing the High-Speed Computer" in the "Harvard Business Review", July-August, 1954, pp 99-107

A description and discussion of the application of Univac at the Major Appliance Division at Louisville, Kentucky, of General Electric Co.; includes many pertinent and useful comments.

Society of Actuaries' Committee on New Recording Means and Computing Devices / Report of the Committee, September 1952 / Society of Actuaries, 208 So. LaSalle St., Chicago, Ill. / 1952, printed, 107 pp

Contains the report given by M. E. Davis, J. J. Finelli, and others at a meeting in New York, on Sept. 25, on how and where automatic electronic computers can be used in a large life insurance company.

Society of Actuaries, M. E. Davis and others / Supplement to the September 1952 Report of the Society of Actuaries Committee on New Recording Means and Computing Devices / Society of Actuaries, 208 So. LaSalle St., Chicago, Ill. / June 1953, photo-offset, 4 pp

This reports several actual demonstrations (with the evidence) of processing life insurance company records on an automatic electronic com-

puter using magnetic tape. The speed of one demonstration was at an effective rate of about 100,000 policies per hour. Also reports an actual demonstration of photoelectric, facsimile scanning of printed records, to produce printed premium notices at the rate of about 1700 per hour.

Society of Actuaries / "Discussion", pp. 190-208, in "Transactions of the Society of Actuaries, Western Spring Meeting No., 1953, No. 4" / Society of Actuaries, 208 So. LaSalle St., Chicago, Ill. / 1953, printed, 19 pp

Wainwright, Lawrence / A Ballistic Engine / University of Chicago, Master's thesis, not published / 1923, 28 pp

An early description of a proposed machine for automatically calculating trajectories. (See footnote, p. 115).

Bibliographies

Controllership Foundation, Inc. / Business Applications of Electronic Machines / Controllership Foundation, Inc., One East 42 St., New York 17, N.Y. / 1954, printed, 46 pp

A most useful bibliography of 179 references to books, articles, and other publications in the field of business applications of electronic machines. It is divided into two main groups: electronics, and advanced transitional uses of electro-mechanical equipment.

The periodicals "Transactions of the IRE Professional Group on Electronic Computers" and "Computers and Automation" (see above) contain many notices and reviews of books and other publications. Notices and reviews appear also in a number of the other periodicals mentioned above. References to other papers and literature appear in many articles, books, and other publications in the field.

VIII:2 ROSTER OF ORGANIZATIONS MAKING AUTOMATIC COMPUTING MACHINES

The first step to be taken when investigating automatic computing machinery is to find out the names and addresses of the organizations currently making or developing such equipment and determine which are the most likely ones to contact for the type of information desired. A list of these organizations giving essential information about them will thus be of considerable assistance. Such a list is presented here; it is hoped that it is complete, or very nearly so.

This list is copyrighted and is reprinted with permission. It appears as the "Roster of Organizations in the Field of Computers and Automation" regularly printed by the monthly magazine "Computers and Automation." Additions and changes in this Roster are there published currently.

Each of the following entries if complete contains: name of the organization and its address / its telephone number / nature of its interest in the field of automatic computing machinery, kinds of activity it engages in, main products in the field, approximate number of its employees, year it was established, and a few comments. Some entries are not complete.

The key to the abbreviations follows:

Size

Ls	Large size, over 500 employees
Ms	Medium size, 50 to 500 employees
Ss	Small size, under 50 employees (no. in parentheses is approx. no. of employees)

When Established

Le	Long established organization (1922 or earlier)
Me	Organization established a "medium" time ago (1923 to 1941)
Se	Organization established a short time ago (1942 or later) (no. in parentheses is year of establishment)

Interest in Computers and Automation

Dc	Digital computing machinery
Ac	Analog computing machinery
Ic	Incidental interests in computing machinery
Sc	Servomechanisms
Cc	Automatic control machinery
Mc	Automatic materials handling machinery

Activities

Ma	Manufacturing activity
Sa	Selling activity
Ra	Research and development
Ca	Consulting
Ga	Government activity
Pa	Problem-solving
Ba	Buying activity

(Used also in combinations, as in RMSa "research, manufacturing and selling activity")

ROSTER

Adalia Limited, Odeon Bldg., 20 Carlton St. East, Toronto, Ont., Canada / Empire 4-2361

Research and consulting services in the application, design, and construction of computers. Ss Se(1952) RCa

Addressograph-Multigraph Corp., 1200 Babbitt Road, Cleveland 17, Ohio / Redwood 1-8000 / and elsewhere

Addressograph sensing plates, composed automatically from punched tape, which will automatically list and total figures. Data written at speeds up to 30 forty-character lines per second; as a byproduct, codes automatically punched into punch cards. Electronic facsimile printers for high-speed copying of typed data contained in unit card records. Ls(8000) Le(1898) Ic RMSa

R. C. Allen Business Machines, Inc., 678 Front Ave., Grand Rapids 4, Mich. / Glendale 6-8541

Adding machines, bookkeeping machines, cash registers, etc. Ls(1250) Me(1932) DIc RMSa

American Automatic Typewriter Co., 614 North Carpenter St., Chicago 22, Ill.

Pneumatically controlled programming and testing devices. Automatic selective typing equipment (Autotypist). Testing machines for typewriters, adding machines, calculating machines. Ms(100) Le(1868) Ic RMSa

American Machine and Foundry, Electronic Division, 1085 Commonwealth Ave., Boston, Mass. / Algonquin 4-4234 /

Magnetic shift registers, digital data-handling equipment; servomechanisms to specifications. Digital servo with 2^{15} quantum units per revolution (shaft to digital conversion). Ls(900) Se(1948) Dc RMSa

Andersen Laboratories, Inc., 39-C Talcott Road, West Hartford 10, Conn. / Adams 3-4491 /

Solid ultrasonic delay lines, computer memories, etc., for computer applications. Ss(30) Se(1950) Ic RMSa

ANelex Corp., Concord, N.H., and 150 Causeway St., Boston 14, Mass. / Richmond 2-3400 /

High-speed printer (1800 characters per second), numerical and alpha-numeric up to 64 characters and line-lengths up to 120 characters. Ms Se(1952) DIc RMSa

Applied Science Corporation of Princeton, P.O. Box 44, Princeton, N.J. / Plainsboro 3-4141 /

Radio telemetering and automatic data conversion. Devices for automatic and semi-automatic reduction and analysis of telemetering and radar data. Analog read-in and read-out devices. Digital storage and computing elements. MADAM (Multipurpose Automatic Data Analysis Machine). Ms(85) Se(1946) DAc RCPMSa

Argonne National Laboratory, Box 299, Lemont, Ill. / Bishop 2-2750, Lemont 800 /

Production of big electronic automatic digital computers for use of Atomic Energy Commission only. ?s Se Dc RMa

Arma Corp., Old Country Rd., Garden City, L.I., N.Y. / Garden City 3-2000 /

Electronic fire-control apparatus. Analog computer components including resolvers, induction generators, etc. Basic weapon and control systems, navigational systems, precision remote control systems. Automatic machine tool and material handling systems. Analog computer components. Ls(6000) Le DASc RMSPa

Armour Research Foundation, Illinois Inst. of Technology, 10 West 35 St., Chicago 16, Ill. / Calumet 5-9600 /

Magnetic recording. Digital, analog and data-handling equipment. Automatic control machinery. Servomechanisms. Instrumentation. Ls(1200) Me(1936) DASCc RCPa

Askania Regulator Co., 240 E. Ontario St., Chicago, Ill. / Whitehall 4-3700 /

Hydraulic and electronic automatic control equipment. Use analog computers; manufacture servomechanisms and automatic controls. Ms(400) Me(1930) SCc RMSPa

Atomic Instrument Co., 84 Mass. Ave., Cambridge 39, Mass. / Eliot 4-4321 /

Analog to digital converters, printers, counter components and controls; shell velocity computation and recording; etc. Ms(100) Se(1947) DACc RMSCa

Audio Instrument Co., Inc., 133 West 14

St., New York 11, N.Y./Oregon 5-7820/

Electronic, mechanical, and optical analog computers. Precision electronic instruments. Time-delay units from 10 to 10,000 milliseconds. Fire control equipment, logarithmic amplifiers. Specialized passive computer which corrects for film nonlinearity in photometric work, etc. Ss(10) Se(1949) DASCc RMSCa

The Austin Co., Special Devices Division, 76 9th Ave., New York 11, N.Y. / Watkins 4-3630 /

Systems and devices for automatic control in commerce and industry; analog, digital, data-handling, servo, electronic, electromechanical. Shaft position indicators and systems; cathode ray indicators and systems. Ls(division, 125; company 25,000) Le(division, 1943; company, 1878) DASCMc RMSa

Automacité Appliqué, 10 rue Saulnier, Paris 9e, France

Automatic control apparatus. Cc RMSa

Automatic Electric Co., 1033 West Van Buren St., Chicago 7, Ill. / Haymarket 1-4300 /

Automatic electrical systems, telephone equipment, relays, stepping switches, etc., for computing machinery and communications companies. Automatic control components. Ls (5700) Le(1892) ICc RMSa

Automatic Signal Division, Eastern Industries, Inc., Norwalk, Conn.

Automatic volume-density traffic controllers. Me Ic RMSa

Automation Engineers Co., Division of Associated Industrial Consultants, 246 West State Street, Trenton, N.J. / Trenton 3-2603 /

Consultants in automatic control machinery and automatic materials handling equipment. Ss(20) Me(1942) DACMc Ca

Avion Instrument Co., Division of American Car and Foundry Industries, Inc., 299 State Highway No. 17, Paramus, N.J. / Oradell 8-4100 /

Digital and analog computing machinery. Magnetic recorders, amplifiers, electronic choppers, test equipment, servomechanisms, automatic control machinery, etc. Ms(160) Se(1946) DASCMc RMSCPa

Baird Associates, 33 University Road, Cambridge 38, Mass. / University 4-0101 /

Spectroscopic analysis equipment; scientific instruments; analog devices, servomechanisms; transistors. Instrumentation for industrial control. Research in physical optics. Ms(200) Me(1937) AISc RMSa

Barber-Colman Co., Rockford, Ill.

Automatic controls, textile machinery, machine tools, etc. Barber-Colman-Stibitz digital computer, operating. Ls(3000) Le Dc RMSa

Beckman Division, Beckman Instruments, Inc., Fullerton, Calif. / Lambert 5-8241 /

Multi-channel digital data-handling systems; 200 channel strain gage recorder. Automatic process control, digital data handling and recording. Ls(1800) Me(1934) DAIc RMSa See also Berkeley Division, Beckman Instruments.

Bell Telephone Laboratories, Murray Hill, N.J. / Summit 6-6000 / and 463 West St., New York 14, N.Y. / Chelsea 3-1000 /

Automatic switching. Bell general purpose computers (relay and electronic, digital and analog) for government use and company's own use. Ls Le DAc RGPa

Bendix Aviation Corporation, Computer Division, 5630 Arbor Vitae St., Los Angeles 45, Calif. / Oregon 8-2128 /

Electronic information-processing machines. Electronic computers; data-processing equipment; automatic control systems; Decimal Digital Differential Analyzer; general purpose digital computers Model G-15A and G-15D. Ms(150) Se(1952, division; 1929, corporation) DACc RMSPa

Bendix Aviation Corp., Pacific Division, North Hollywood, Calif.

Telemetering systems. Digital systems, controls, and components. Ls(2500) Le(1915, company; 1937, this division) Ic RMSa

Benson-Lehner Corp., 2340 Sawtelle Blvd., West Los Angeles 64, Calif. / AR-93723 BR-21197 /

Automatic and semi-automatic devices (both analog and digital) for computing, data analyzing, data reduction, optical measuring, guided missile analysis, etc. Oscillogram trace readers, plotters, etc. Commercial applications of industrial control devices. Ms(118) Se(1950) DAc RCMSa

Berkeley Division, Beckman Instruments, Inc., 2200 Wright Ave., Richmond, Calif. / Landscape 6-7730
EASE computer (Electronic Analog Simulating Equipment) for solving equations, simulating systems, etc. Se Ac RMSa

Edmund C. Berkeley and Associates, 36 West 11 St., New York 11, N.Y. / Algonquin 4-7675 / and 815 Washington St., Newtonville 60, Mass. / Decatur 2-5453 or 2-3928 /
Logical design, applications, marketing, etc., of automatic information-handling machinery. Publisher of "Computers and Automation". Small one-of-a-kind computers (Simon) and robots (Squee); more under construction. Courses, publications. Ss Se(1948) Dc RCMSa

Berkshire Laboratories, 732 Beaver Pond Road, Lincoln, Mass. / Waltham 5-7000 /
Special computer components. Ss Se(1949) IAc RMCa

Birkbeck College, University of London, 21 Torrington Sq., London W.C. 1, England / Langham 1912 /
Maker of ARC, APEXC, and SEC digital computers; electronic digital computers. Ss(10 to 20) Se(1946) Dc RCPa

Boeing Airplane Company, Industrial Products Division, Seattle 14, Wash. / Mohawk 4444 /
Boeing Electronic Analog Computer, Associated non-linear equipment. Complete line of auxiliary equipment, including function generator and electronic multiplier. Ls(37,000) Le(1916) Ac RMSa

Bradley Laboratories, Inc., 168 Columbus Ave., New Haven, Conn. / Main 4-3123 /
Selenium rectifier kits, high temperature rectifiers. Ms Me Ic RMSa

British Tabulating Machine Co., Ltd., 17 Park Lane, London W. 1, England / Hyde Park 8155 /
Punched card machines. Ls(4500) Le (1908) Dc RCPMSa

Brush Electronics Co., 3405 Perkins Ave. Cleveland 14, Ohio (formerly Brush Development Co.)
Recording analyzers. Magnetic tape, heads, and drums. Computer components. Ls(1300) Le(1921) Ic RMSa

Bull S. A. Compagnie des Machines, 94 Avenue Gambetta, Paris 20e, France / MEN 8158 /
Punch card machines. Commercial electronic computers and card-programmed scientific computers. Producing about 10 electronic computers a month; 100 currently in operation. Ls(2500) Me(1931) Dc RMSa

Bureau of the Census, Washington 25, D.C. /
Tabulation of statistical data by special machines designed and built for own use, by commercial punch-card equipment, and by electronic computing system (the Univac). Ls (1100 in Machine Tabulation Division) Le(1890 in punch card field) Dc Ga

Burlingame Associates, 103 Lafayette St., New York 13, N.Y. / Digby 9-1240 /
Analog computers, servo analyzers, servo-control devices, digital voltmeters, etc. Ss(35) Me(1928) AIc Ca

Burroughs Corporation (formerly Burroughs Adding Machine Co.) 6071 Second Ave., Detroit, Mich. / Triangle 5-2260 / —headquarters; Burroughs Corporation Research Center (formerly Research Division), Paoli, Pa.; and elsewhere /
Automatic electronic digital computer, UDEC. Adding machines, bookkeeping machines, etc. Burroughs Laboratory Computer, an electronic digital test computer, assembled from pulse control units. Fast access magnetic core memory. Pulse control components, servomechanisms, etc. This company owns Control Instrument Co. Ls(18,000) Le(1896) DSc RMSPa

California Computer Products, 3927 West Jefferson Blvd., Los Angeles 16, Calif.
Digital point plotter (CCP 701) and other equipment. DAc RMSa

Clary Multiplier Corp., 408 Junipero St., San Gabriel, Calif.
Adding and calculating machines, cash registers, electronic counters, analog-digital converters, input and output equipment for computers, data-reduction systems. Ls(1500) Me(1939) DAc RMSa

Coleman Engineering Co., 6040 West Jefferson Blvd., Los Angeles 16, Calif. / Vermont 9-7549 /
Digital data handling systems and

components; "Digitizer", device for converting rotational shaft positions into electrical contact settings; etc. Ms(100) Se(1951) DIc RMSa

Commercial Controls Corp., 1 Leighton Ave., Rochester 2, N.Y. / Culver 5800 /
Mailroom equipment. "Flexowriter" electric typewriter with punched paper tape control. Ls Le Ic RMSa

Commonwealth Scientific and Industrial Organization, Radiophysics Division, Sydney, New South Wales, Australia
Maker of CSIRO Mark I electronic digital computer of Inst. for Advanced Study type. DAc RCGPa

Computer Company of America, Division of Bruno-New York Industries Corp., 149 Church St., New York 7, N.Y. / Cortlandt 7-1450 (formerly Comp. Corp. of America)
Analog computers, differential analyzers, specialized computers and accessories. Ms(125) Se(1942) DAc RMSPa

Computer Control Co., 92 Broad St., Babson Park 57, Mass. / Wellesley 5-6220 / and 1429 Promenade Highway, Santa Monica, Calif. /
Computers and computer components, digital data-handling systems, solid delay-line acoustic memory, computer test equipment, dual beam conversion kits, specialized systems and instrumentation. Operating and servicing Raydac at Pt. Mugu, Calif. Ss(35) Se(1952) Dc RMSCa

Computing Devices of Canada, Ltd., P.O. Box 508, Ottawa, Ont., Canada / Parkway 2-6541 /
Custom-built digital and analog computers, automatic navigation systems, electronic laboratory test equipment, simulators, servomechanisms. Research and development in instrumentation, automatic control, business and scientific sorting, systems analysis. Ms(200) Se(1948) DASCc RCPMSa

Computyper Corp., subsidiary of Friden Calculating Machine Co., Inc., San Leandro, Calif.
See Friden Calculating Machine Co.

Consolidated Engineering Corp., 300 N. Sierra Madre Villa, Pasadena 8, Calif. / Sycamore 6-0173 /
Digital and analog data-handling and conversion systems (Sadic, Millisadic, etc.). Automatic translator magnetic tape to punched card. Computers now manufactured by their affiliate, Electro Data Corp., which see. Ls(1400) Me(1937) Dc RMSa

Control Instrument Co., 67 35th St., Brooklyn, N.Y. / Sterling 8-0658 /
Fire-control equipment. 1000-line-a-minute tabulator. Digital and analog machines and components. Now a subsidiary of Burroughs Corporation. Ls(1200) Me(1934) DAc RMSa

Convair, a Division of General Dynamics Corp., General Offices: San Diego 12, Calif. / Cypress 6-6611 /
Research and development in the missile, electronics, and airframe fields. The Charactron, a computer output device for "debugging", tactical display, etc., converting coded information into tabular or graphic alphanumeric information on a cathode ray tube screen. Digital automatic control; analog to digital conversion units. Large analog computer installations. Ls(44,000) Me(1925) Ic DAIc RMSa

Cook Research Laboratories, Division of Cook Electric Co., 2700 Southport Ave., Chicago 14, Ill. (mail address), 8100 Monticello Ave., Skokie, Ill. (location) / Keystone 9-2060 and Orchard 3-9200 /
Magnetic data-recording systems; digital, analog, and hybrid information-processing systems — particularly for aircraft and airborne applications. Basic and industrial research in servomechanisms, air research, weather reconnaissance, guided missiles, etc. Ms (380) ?e DAIc RCa

Curta Calculator Co., 3851 West Madison St., Chicago 24, Ill.
Eight-ounce, hand-powered, rotary "brief-case" calculator; adds, subtracts, multiplies, divides; totals to 15 decimal places; made in Lichtenstein. Ss(10) Se(1952) Dc Sa

Daco Machine Co., Brooklyn, N.Y. / Ulster 5-8350 /
Computing controls for machine tools. Cc RMSa

Davies Laboratories, Inc., 4705 Queensbury Road, Riverdale, Md. / Appleton 7-1133 /
Automatic data-reduction equipment. Magnetic tape data recorders. Ms(85)

Se(1946) Ac RMSCa

The de Florez Co., 116 East 30 St., New York, N.Y. / Murray Hill 6-5730 /
Magazine subscription fulfillment problem, etc. Ss Se DAc RCa

Doelcam Corp., 1400 Soldiers Field Rd., Boston 35, Mass. / Algonquin 4-5200 /
Servomechanisms, amplifiers, etc. Ls(800?) Me SIc RMSa

Eckert-Mauchly Div., Remington Rand, Inc., 3747 Ridge Ave., Philadelphia, Pa. / Baldwin 3-7300 / and elsewhere /
All purpose electronic digital computers. Univac Factronic System. Ls (600) Se(1946) Dc RCMa Also see Remington Rand, Inc.

Thomas A. Edison, Inc., Instrument Division, 22 Lakeside Ave., West Orange, N.J. / Orange 3-6800 /
Automatic control components, time delay relays. Ms(360 in division; 4000 in company) Le(1888) Ic RMSa

Electro-Data Corporation, 717 North Lake Ave., Pasadena 6, Calif. / Sycamore 8-6761, Ryan 1-8335 /
Automatic electronic digital computers. Electronic data-processing equipment for scientific, industrial and commercial applications. Affiliate of Consolidated Engineering Corp., which see. Ms(150) Se(1950) Dc RMSPa

Electronic Associates, Inc., Long Branch, N.J. / Long Branch 6-1100 /
General purpose precision analog computers, special purpose analog computers, analog computer components, digital-to-analog converter, digital plotting system (Dataplotter). Automatic control of all machine tools. Ms(360) Se(1945) DACc RMSa

Electronic Computer Div. of Underwood Corp., 3510 36th Ave., Long Island City 6, N.Y. / Exeter 2-3400 /
Constructing five types of electronic digital computers (ELECOM-100, -120A, -125, -200, and a data-handling computer). Delay lines, decade delay lines, pulse transformers, magnetic recording heads, magnetic drums, D.C. plug-in amplifiers. Ms(200) Se(1949) Dc RMSa

Electronic Control Systems, Inc., 2138 Westwood Blvd., Los Angeles 25, Calif. / Arizona 7-0244 /
Special purpose computers for military and industrial use; industrial process and machine control systems; automatic test equipment. Ss(20) Se(1953) DASCc RMCSa

Electronic Engineering Co., 180 South Alvarado St., Los Angeles 57, Calif. / Dunkirk 2-7353 /
Analog computing machinery. Analog-to-digital-to-analog converters. Polar-to-rectangular-to-polar converters. Servomechanisms. Ms Se DAc RMSa

Elliott Bros. (London) Ltd., Century-Works, Lewisham, London, S.E. 13, England, and Computing Machine Division, Elstree Way, Borehamwood, Herts., England / Tideway 3232, Elstree 2040 /
Digital and analog computers; servomechanisms; components, instrumentation and control for process industries. Ls(3500) Le(1800) DASCc RMSCPa

Engineering Research Associates, Div. of Remington Rand, Inc., 1902 West Minnehaha Ave., St. Paul, Minn., and 510 18th St. South, Arlington, Va. / Nestor 9601, St. Paul /
Automatic digital computers; ERA 1101, 1102, 1103, electronic digital computers; Speed Tally; CAA Flight Plan Storage Systems; the Logistics Computer. Magnetic storage systems, including magnetic heads, magnetic drums, etc. Shaft position indicator systems, self-recording accelerometers, analog magnetic recording systems, data-handling equipment, special purpose communications equipment, pulse transformers. Ls (1050) Se(1946) Dc RMCPSa Also see Remington Rand, Inc.

Engineers Northwest, 2835 Nicollet Ave., Mineapolis 8, Minn. / Re 5541 /
Test-scoring machines and equipment. Ss(20) Se(1945) DAc RCMa

English Electric Co., Stafford, England.
Manufacturers of fully engineered versions of ACE (see National Physical Laboratory). Ls Le DIc RMSa

Epsco, Inc., 126 Massachusetts Ave., Boston, Mass. / Kenmore 6-0601 /
Magnetic shift registers, transistors, delay lines, and other components for computers, systems, automatic control, etc. Ss(20) Se(1954) DIc RMSCa

Fabrica Addizionatrice Italiana S.S., Viale Umbria 36, Milan, Italy.

Desk calculators to add, subtract, multiply, divide, print. Dc RMSa

Facit, Inc., 500 5th Ave., New York 36, N.Y. (subsidiary), Stockholm, Sweden (headquarters), and elsewhere /
Calculators, adding machines, typewriters, etc. (in 1390 A.D., copper mining). Ls(4000) Le(1390 A.D.) Dc RMSa

Farrand Optical Co., Bronx Blvd. and 238 St., New York 70, N.Y. / Fairbanks 4-2200 /
Gunfire control apparatus, rangefinders, optical and electronic sighting equipment, automatic trackers, infrared search and scanning systems, analog-digital converters, analog computers, etc. Ls(800) Le(1918) DASCa RMSCa

Felt and Tarrant Mfg. Co., Comptometer Div., 1735 No. Paulina St., Chicago 22, Ill. / Brunswick 8-5000 /
Adding-calculating machines, key-driven, electric and non-electric. Comptometer. Electronic dictating machines. Ls(1700) Le(1886) Dc RMSa

Ferranti Electric, Inc., 30 Rockefeller Plaza, New York 20, N.Y. / Circle 7-0911 / agent for Ferranti Electric Ltd., Moston, England, and Mount Dennis, Toronto, Canada.
Complete electronic digital computers (Ferranti; also called "Manchester Universal Electronic Computer") High-speed photo-electric tape reader, which can read up to 200 characters per second. Magnetic drum and electrostatic storage components, etc. Ls (10,000) Le(1896) Dc RMSa

Fischer and Porter Company, 330 Warminster Road, Hatboro, Pa. / Osborne 5-6000 /
Automatic instrumentation, including: measurement of a variable at the point of process; transmission of data, central collection, and display; data reduction systems using a mechanical digital data output, etc. Automatic multiple readout systems, converters, computers. Ls(850) Me(1937) DACc RMSa

Ford Instrument Co., Div. of The Sperry Corporation, 31-10 Thomson Ave., Long Island City 1, N.Y. / Stillwell 4-9000 /
Gunfire control apparatus. Analog computers and components, magnetic amplifiers, servo motors, differential and integrator elements. Instruments for shipborne and airborne armament and navigational control. Ls(3800) Le (1915) ASc RMPCSa

The Franklin Institute Laboratories for Research and Development, 20th St. & Benjamin Franklin Parkway, Philadelphia 3, Pa. / Locust 4-3600 /
Fire-control equipment. Special purpose analog computers, large and small scale. Digital computer components. Prototype construction. Ms(325) Se (1946) DAc Ra

Friden Calculating Machine Co., Inc., San Leandro, Calif.
Desk calculating machines. Computyper. Add-Punch machine. Automatic equipment for punching codes in tape. Ls(2000) Me(1934) Dc RMSa

General Ceramics Corporation, Keasbey, N.J. (near Perth Amboy) / Valley 6-5100 /
Magnetic cores and ferrites for computer components; toroidal ferrite cores as memory devices for computers, as used in Whirlwind (MIT) computer new rapid memory; technical ceramics, insulators, etc. Ls(500) Le (1906) Ic RMSa

General Controls, 801 Allen Ave., Glendale 1, Calif.
Automatic controls (pressure, temperature, level, flow). Ls Cc RMSa

General Cybernetics Associates, P.O. Box 987, Beverly Hills, Calif. / Vermont 9-0544 /
Industrial automation, computers, instrumentation, communication, industrial electronics; linear displacement transducers, digital converters, punch-card-to-tape devices, electronic gages for automation processes, medical electronics research and development; etc. Ss(18) Se(1953) RMSCa

G. M. Giannini & Co., Inc., Laboratory Apparatus Division, 918 Green St., Pasadena, Calif. / Ryan 1-7512 /
Digitizing analog devices, etc. Ms (100) Se (1952) DAc RMSa

Goodyear Aircraft Corp., Dept. 931, Akron 15, Ohio / Republic 3-6361 /
Goodyear electronic differential analyzers, (GEDA line of analog computing equipment). Ls Me Ac RMSa

Haller, Raymond, and Brown, Inc., State

College, Pa. / Ad 7-7611 /
Electronic digital computer for solution of up to 1200 simultaneous equations, using magnetic drum and tape. Research and development on computer components, analog computers, electronic and electromechanical systems. Engineering analysis, operations research, electronic development. Ms (200) Se(1947) Dc Ra

Harvard University, Harvard Computation Laboratory, Cambridge 38, Mass.
Harvard Mark I, II, III, IV calculators for Navy, Air Force, and own use. Ms Se Dc RPMa

Hillyer Instrument Co., 54 Lafayette St., New York 13, N.Y. / Digby 9-4485 /
Simulators, servomechanisms, sensing, computing, and actuating systems. Automatic machine controls. Ms(100) Se(1945) DAICs RMSa

Hogan Laboratories, 155 Perry St., New York 14, N.Y. / Chelsea 2-7855 /
Circle computer, completed and under test; manufactured by this company. Digital high-speed printers. Associated with Nuclear Development Associates. MS(60) Me(1929) Dc RMSa

Hughes Research and Development Laboratories, Hughes Aircraft Co., Culver City, Calif. / Texas 0-7111 /
Automatic data-handling systems for commercial and military applications. Industrial control systems. Small, automatic electronic digital and analog computers for airborne use. Fire-control equipment. Aircraft control. Guided missiles. Ls(15,000 company; 4,000 Res. and Devt. Labs; 400 computers) Me(1937) DAc RMSa

Imperial College, Mathematics Dept., Computer Section, Huxley Bldg., Exhibition Road, So. Kensington, London, England
Automatic digital relay computer constructed and in operation; constructing a second computer with neon tube storage. Ss Le(1922) Dc RMa

Institut Blaise Pascal, Laboratoire de Calcul Analogique, Paris, France:
Combined with the Institut Blaise Pascal, Laboratoire de Calcul Mecanique, which see.

Institut Blaise Pascal, Laboratoire de Calcul Mecanique, 25, Avenue de la Division Le Clerc, Chatillon-sous-Bagneux (Seine), France.
Constructing a digital calculator. Ss(9) Me(1939) Dc RPa

Institute for Advanced Study, Princeton, N.J.
Big fast electronic digital calculator, for own use. Dc RPMa

Intelligent Machines Research Corp., 1101 Lee Highway, Arlington, Va. / Jackson 5-6400 /
Devices for reading characters on paper, etc. Pattern interpretation equipment. Sensing mechanisms. Digital computer elements. Ss(17) Se(1951) Dc RCMSa

International Business Machines Corp., 590 Madison Ave., New York 22, N.Y. / Plaza 3-1900 / and elsewhere.
Punch card machines. Type 650, Magnetic Drum Calculator. IBM Electronic Data Processing Machines, Type 701, Type 702 and Type 704 (magnetic tape, magnetic drum, electrostatic storage). Card Programmed Calculator. Electronic calculating punch Type 604 and Type 607. Data processing equipment. Automatic Source Recording Equipment. Ls(42,000) Le(1911) Dc RMSa

International Telemeter Corp., 2000 Stoner Ave., Los Angeles 25, Calif. / Arizona 8-7751 /
Systems and devices for clerical and control applications. High-capacity rapid-access ferrite core memories. High-density photographic information storage. Community TV system equipment; pay-as-you-go TV. Ms(200) Se(1951) DCc RMSa

International Telephone and Telegraph Corp., 67 Broad St., New York 4, N.Y. / Bowling Green 9-3800 /
Equipment for automatic control of repetitive processes; clerical or industrial work, such as inventories. Fully pneumatic tube system, by dialing. Ls(96,000) Le DASCMc RMSCPa

Jacobs Instrument Co., 4718 Bethesda Ave., Bethesda 14, Md.
High-speed small, compact digital computers (Jaincomp A, B, B1, B2, C). Pulse transformers, delay lines, magnetic storage systems. Input and output devices. Complete instrument systems. Ss(30?) Se(1948) DASCc RMSa

Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Drive, Pasadena 3, Calif.

Analog, digital, and data-handling systems. Research and development in jet propulsion and missile guidance Ls(1000; about 50 on computers) Me (1942) DAc RCPa

Kearfott Co., Inc., Clifton, N.J. / Gregory 2-1000 /

ADAC (Analog-digital-analog-converter: servoed and direct drive); etc. Ls (3000) Le(1916) ISc RMSa

Ketay Manufacturing Co., 555 Broadway, New York 12, N.Y. / Digby 9-2717 / and elsewhere

Automatic control systems; synchros, servo-motors, resolvers; magnetic, electronic, and resolver amplifiers. Electronic equipment; servomechanisms; gears and components. Ls(2000) Se(1943) CISc RMSa

A. Kimball Co., 307 West Broadway, New York 13, N.Y. / Canal 6-2300 /

Machine for printing and punching garment tags and specific type tickets. Input mechanisms. Ms(200) Le (1876) Ic RMSPa

The Kybernetes Corp., Division of Self-Winding Clock Co., 1100 Raymond Blvd., Newark 5, N.J. / Mitchell 2-0957 /

Devices employing high-speed television techniques for: making printed coded characters on paper with automatically translatable coding; reading printed code and translating it into signals; sorting media carrying printed codes, etc. Systems for multiplexing, scanning, telemetering, timing, television, etc. Ms(150) Le(1886, parent company) ICc RMSCa

Laboratory for Electronics, 75 Pitts St., Boston 14, Mass. / Richmond 2-3200 /

Analog and digital computers, special computers to suit customer requirements, delay lines (mercury, quartz), plug-in packages for computer applications, etc. Ls(700) Se(1946) DAc RMSa

Lanston Monotype Machine Co., Barrett Adding Machine Div., 24th & Locust Sts., Phila. 3, Pa. / Locust 7-4614 /

Adding, subtracting, and printing, desk calculators. Dc RMSa

L'Electronique Industrielle, 55 Blvd de la Republique, Livry-Gargan, Seine-et-Oise, France.

Automatic electronic measurement, counters, controls. Cc RMSa

Librascope, Inc., 808 Western Ave., Glendale, Calif. / Ch 5-2677 /

Mechanical and electrical computers. Computing and controlling equipment for military applications and for banking, department stores, inventory and production control, etc. Airborne digital computers. General purpose computer under construction. All phases of data-handling. Ls(1200; approximately 350 on digital computers) Me (1937) DASc RMSa

Arthur D. Little, Inc., 30 Memorial Drive, Cambridge 42, Mass. / University 4-9370/

Analog digital converter, "Automatic Digital Recorder of Analog Data" (ADRAD). Conversion and input devices. Ls(800) Le(1886) Ic RCa

Log Abax S.A.R.L., 146 Avenue des Champs Elysées, Paris 8, France / Elysées 61-24 /

Collaborating with Institut Blaise Pascal on computing devises. 99 register automatic accounting machine. Ms(400) Se(1949) Dc RMSa

Logistics Research, Inc., 141 So.Pacific Ave., Redondo Beach, Calif. / Oregon 8-7108 /

Digital computers and computing systems (ALWAC). Data-reduction and data-handling systems, input and output equipment; automatic graph plotters; automatic curve followers; large scale magnetic memories with "air-floating" magnetic heads, etc. Ss(33) Se(1952) DIc RMSa

Marchant Calculators, Inc., Oakland 8, Calif.

Automatic electric calculators (desk type). Marchant-Raytheon Binary-Octal Calculator (desk type). Marchant "Miniac" electronic digital computer. Computer components. Data processing equipment. Ls(2500) Le(1910) DIc RMSa

Marchant Research, Inc., 1475 Powell St., Oakland 8, Calif. (subsidiary of Marchant Calculators, Inc.) / Piedmont 5-7453 /

Electronic digital computers (including Miniac). Magnetic storage systems, magnetic heads, data processing equipment including analog-to-digital converter, computer components.

Ss(55 this division) Se(1950 this division) Dc RMSa

Massachusetts Institute of Technology, Digital Computer Laboratory, 211 Mass. Ave. / Eliot 4-3311 / also Center of Analysis; Cambridge 39, Mass.
"Whirlwind" electronic digital computer. Ms(300+) Se(1945?) DAc RCPa

Mathematisch Centrum, 2e Boerhaavesstraat 49, Amsterdam, Netherlands.
Relay computer in use; electronic computer under construction. Ms(60) Se(1946) Dc RCPa

The W. L. Maxson Corp., 460 West 34 St., New York 1, N.Y. / Longacre 5-1900 / and elsewhere
Servomechanisms, analog computers, and digital computers for fire control, navigation, etc. Automatic control machinery. Ls(3000) Me(1935) DASCc RMSa

Mellon Institute of Industrial Research, Multiple Fellowship on Computer Components, University of Pittsburgh, Pittsburgh 13, Pa.
Ss(6) Se(1950) Dc RCa

Mid-Century Instrumatic Corp., 611 Broadway, New York 12, N.Y. / Spring 7-4016 /
Analog computers; six-channel recorders; electronic function generators; electronic multipliers, etc. Ss(27) Se (1950) Ac RMSa

William Miller Instruments, Inc., 325 No. Halstead Ave., Pasadena 8, Calif.
Milac analog computer. Electronic instruments for precision testing and measurement. Ac RMSa

Minnesota Electronic Corp., 3101 East 4 St., Minneapolis, Minn. /
Digital and analog computers. Magnetic components, magnetic decision elements. Data reduction systems, telemetering. Ss(35) Se(1946) DAIc RMSa

Minneapolis-Honeywell Regulator Co., Industrial Division, 4580 Wayne Ave., Philadelphia 44, Pa. / Michigan 4-8300 /
Automatic controllers. Brown Instruments. Servo components used in computers. Recording and indicating instruments and control equipment, etc. Amplifiers, converters, balancing motors, potentiometers, etc. Ls(3500) Le(1859) RMSa

Monrobot Corp., Morris Plains, N.J. / Morristown 4-7200 /
Monrobot automatic electronic digita computers. Subsidiary of Monroe Calculating Machine Co. Ss(32) Se(195 Dc RMSa

Monroe Calculating Machine Company, Orange, N.J. / Orange 3-6600 / and elsewhere.
Desk calculating machinery for adding, calculating, and bookkeeping. See also Monrobot Corp. Ls(4000) L (1912) Dc RMSa

Moore School of Electrical Engineering, Univ. of Pennsylvania, Philadelphia, Pa. / Evergreen 6-0100, X981 /
Place where Eniac and Edvac electronic digital computers were constructed. Analog and digital equipment; simulators. Ms(80) Me(1923) DAc RCPa

F. L. Moseley Co., 409 North Fair Oaks, Pasadena, Calif. / Ryan 1-8998 /
"Autograf" X-Y Recorder, point plotter, curve follower, etc. Ss(30) Se(1951) Ic RMSa

Mountain Systems, Inc., 94 Lake St., White Plains, N.Y. / White Plains 9-0714 /
Data processing systems and digital computer systems. Ss Se Dc RMSCa

National Bureau of Standards, Applied Mathematics Division, Washington 25, D.C. / Em 2-4040 /
(1) Numerical Analysis Section: Ss(10) Se(1954) Dc RGa
(2) Computation Laboratory: SEAC (Bureau of Standards Eastern Automatic Computer). Ms(50) Me(1938) Dc CPGa
(3) Statistical Engineering Laboratory: Ss(20) Se(1946) Dc RCPGa
(4) Mathematical Physics Section: Ss (10) Se(1954) Dc CPGa

National Bureau of Standards, Electronics Division, Electronic Computers Laboratory, Washington 25, D.C.
Digital computers, data processing systems, input-output devices. Storage elements, transistors, diodes, delay lines, etc. Have designed and assembled Seac and Dyseac electronic digital computers, etc. Ms(110) Se(1946) Dc RCMBGa

The National Cash Register Co., Electronics Division, 3348 West El Segundo

Blvd., Hawthorne, Calif. / Osborne 5-1171 /
Digital computers, data processing machines, decimal digital differential analyzers, computer components, input-output devices, computing systems. CRC 102-A and 102-D general purpose computers and other computers. Ms(350) Se(1950) Dc RCMSa

National Physical Laboratory, Control Mechanisms and Electronics Division, Teddington, Middlesex, England.
Digital computers, electronic simulators, data recording. Designer and builder of the Pilot Model of ACE (Automatic Computing Engine). Collaborates with English Electric Co. Ls(1000; this division, 40) Le(1900) DIc RCPMa

Notifier Manufacturing Co., 239 South 11 St., Lincoln 8, Nebraska / Lincoln 5-2946 /
Automatic control machinery for fire alarms. Automatic control circuits, computer circuits, switching circuits. Memory and pulse storing devices, transistor devices. Ss(35) Se(1949) CIc RMSCa

Nuclear Development Associates, 80 Grand St., White Plains, N.Y. / White Plains 8-5800 /
Circle Computer design and sales; special purpose data-handling systems, and system design. Associated with Hogan Laboratories. Ms(100) Se (1948) DIc RMSa

Olivetti Corp. of America, 580 Fifth Ave., New York 36, N.Y. / Judson 2-0637 / and Ing. C. Olivetti & C., S.P.A., Ivrea, Italy.
Desk adding, calculating, and printing machines. Fully automatic printing calculators. Ls(6000) Le(1908) Dc RMSa

Ortho Filter Corp., 196 Albion Ave., Paterson 2, N.J. / Mulberry 4-5858 /
Pluggable units for computers, cathode ray amplifiers, power supplies, wiring of complete racks, etc. Ss(43) Se(1946) Ic RMSa

Pennsylvania State College, X-Ray and Solid State Lab., Dept. of Physics, State College, Pa.
X-RAC computer for crystal electron density functions. S-FAC for structure factor interpretations. Ms(55) Se(1947) Ac RPa

George A. Philbrick Researches, Inc., 230 Congress St., Boston 10; Mass. / Liberty 2-5464 /
Philbrick electronic analog computing equipment and components. Ss(5) Se (1946) Ac RCMSa

Phillips Control Corp., Joliet, Ill. / Joliet 3-3431 /
Relays for computers, etc. Ms(350) Se(1946) Ic RMSa

Potter Instrument Co., 115 Cutter Mill Rd., Great Neck, N.Y. / Great Neck 2-9532 /
Electronic counters. Magnetic tape handler; digital printer. Shift registers. Magnetic core memory. Random access memory. High-speed printer ("Flying Typewriter"). Analog-to-digital converter. Ms(100) Se(1942) Dc RMSa

Powers-Samas Accounting Machines, Ltd., England.
Punch card tabulating equipment using small, medium, and standard cards. Agency is Underwood Corp., which SEE. Ls(6000) Le(1916) DIc RMSa

Productions Electroniques, 8 rue Laugier, Paris 17, France.
Collaborating with Institut Blaise Pascal on magnetic recording devices. Ic RMSa

Radio Corporation of America, Tube Division, 415 South 5 St., Harrison, N.J./ Humboldt 5-3900 /
Tubes, transistors for computers. Ls Le Ic RMSa

Ramo-Wooldridge Corp., 6214 Manchester Blvd., Los Angeles 45, Calif.
Digital computers and components, etc. ?s Se(1954) DIc RMSa

The Rand Corporation, 1700 Main St., Santa Monica, Calif.
Electronic digital computer (Johnniac) constructed and operating. Ls(600) Se(1946) DAIc RCPa

Raytheon Manufacturing Co., Waltham, Mass. / Waltham 5-5860 /
Electronic computer systems for general accounting and data-processing operations, and for general scientific applications (RAYDAC). Magnetic-core coincident-current matrix memory systems, magnetic shift registers, binary and decade counters, magnetic core logical components and subsystems, tape-handling mechanisms, magnetic recording heads, magnetic amplifiers. Comput-

ing services to analyze and process problems in operations research, applied mathematics, engineering, and general business accounting by digital computer. Machine control, radar, sonar, communications, fire control, microwave and telemetering equipment, power and receiving tubes, diodes, transistors. Ls(20,000) Me (1925) DAc RMSPa

J. B. Rea Co., Inc., 1723 Cloverfield Blvd., Santa Monica, Calif. / Exbrook 3-7201 /
Automatic control systems; high-speed analog-to-digital converter (Reacon); analog and digital computing facility; etc. Ms(60) Se(1951) DSCc RMSCa

Reeves Instrument Co., 215 East 91 St., New York 28, N.Y. / Trafalgar 6-6000 /
Fire-control equipment. "REAC" electronic analog computers. Ls Me Ac RMSa

Remington Rand, Inc., 315 4th Ave., New York 10, N.Y. / Spring 7-8000 / and elsewhere /
Digital computers (Univac System, ERA 1101 Electronic Computer System, ERA 1103 Electronic Computer System); analog computers; special purpose computers. Card-to-tape and tape-to-card converters. Servomechanisms, magnetic drum storage systems, input and output devices. Adding and calculating machines. Punched-card accounting machines and other accounting machines, etc. SEE also Eckert-Mauchly Division and Engineering Research Associates Division. Ls (over 30,000; 1800 on computers) Le DASc RCMSa

Robotyper Corporation, 125 Allen St., Hendersonville, N.C. / Hendersonville 4246 /
Automatic typing equipment that can be associated with any electric typewriter, using a record roll pneumatically operated. Ic RMSa

Servo Corporation of America, New Hyde Park, N.Y. / Fieldstone 7-2810 /
Servomechanisms. Automatic controls. Analysis and synthesis for controls manufacturers. Temperature controls by infra-red radiation. Industrial controls. Servo components and test equipment. Analog and digital computers. Ms(350) Se(1946) DASCc RMSa

Servomechanisms, Inc., Post & Stewart Ave., Westbury, L.I., N.Y., and 316 Washington St., El Segundo, Calif. / Westbury 7-2700 and El Segundo 1517 /
Automatic electronic and electromechanical control systems and components, analog computers, instrumentation. Ls(700) Se(1946) ASICc RMSa

Shepard Laboratories, Summit, N.J.
High-speed typer (up to 1800 characters per second). Ss Se(1950) DIc RMSa

Société d'Electronique et d'Automatisme, 138 Blvd de Verdun, Courbevoie, Seine, France / Défense 41-20 /
Analog and digital computers and components. Servomechanisms; electronic equipment for machine tools; electronic recorders. Analog computer OME-L2. General purpose digital computer CAB 2.022. Ms(320) Se(1948) DASc RMSa

Société des Servomechanismes Electroniques, 1 rue Chanez, Paris 16e, France.
Sc RMSa

Soroban Engineering, Inc., Box 117, Melbourne, Fla.
Electronic digital computers of the FLAC and SEAC type; computer auxiliaries such as high-speed tape perforators (240 characters per second), coded automatic keyboards, automatic format tabulators, etc. Ss Se(1953) Dc RMSa

Southern Electronics Corporation, 239 West Orange Grove Ave., Burbank, Calif. / Victoria 9-3193 /
Precision polystyrene capacitors. Ss (55) Se(1951) Ic RMSa

Sperry Gyroscope Co., Great Neck, N.Y. / Fieldstone 7-3600 /
Ordnance; fire-control equipment. Automatic controls. Navigation equipment, sea and air. Radar, Loran, gyrocompasses, precision instruments. Ls(18,000) Le(1910) Ac RMSa

Swedish Board for Computing Machinery, Drottninggatan 95A, (P.O. Box 6131), Stockholm 6, Sweden / Stockholm 23 55 90 /
State central institution for research, development, and computation service on large-scale machines. Operates two computers, BARK and BESK, designed and built by the Board. They have run commercially, BARK since

July 1950, and BESK since March 1954. BARK is a binary, automatic relay computer, orders set up on a plugboard, parallel-operating, three- (four-) address system. BESK is a binary, electronic sequence computer, storing orders and data in a parallel Williams memory or in a magnetic drum memory, one-address system, parallel-operating. Research on numerical analysis; development of new computers. Ss(30) Se(1949) Dc RMCPa

Sylvania Electric Co., Radio and Television Div., 70 Forsyth St., Boston 15, Mass. / Kenmore 6-8900 / and elsewhere.
Electronic digital computers using printed circuit techniques. Subassemblies of diodes and triodes. Computer components. Ls(2200; this division 190) Le(1901; this division 1949) DAc RMSa

Taller and Cooper, 75 Front St., Brooklyn, N.Y. / Ulster 8-0500 /
Data recording and conversion system, printers, perforators, analog to digital converters. Function generators, computers. Mechanical function generator control of machine tools and allied mechanisms. Toll equipment for bridges, highways, turnpikes. Ms(350) Me(1926) DIc RMSa

Tally Register Corp., 5300 14th Ave. N.W., Seattle 7, Wash. / Dexter 5500 /
Special purpose business machines; electro-magnetic pulse counters and pulsed relays; high-speed data reduction systems for telemetering applications; digital-input, multiple-symbol X-Y plotter with continuous grid printing; numeric printing tape punch; printing transfer key punch. Ss(15) Se (1948) DICMc RMSCa

Technitrol Engineering Co., 2751 North 4 St., Philadelphia 33, Pa. / Garfield 6-9105 /
Computing and control equipment. Complete digital systems. Components, pulse transformers. Electrical and acoustic delay lines. High-speed memories. Time serial computers. Ms (90) Se(1947) DAc RMSa

Telecomputing Corp., 133 E. Santa Anita Avenue, Burbank, Calif. / Charleston 0-8161 /
Automatic data reading, recording, and plotting equipment. Automatic business data accumulation and analysis equipment; multiple access storage systems. Ms(250) Se(1947) DCMc RMSPa

Telequipment Corporation, Sea Cliff, N.Y. / Glen Cove 4-2900 /
Equipment for attaching to an electric typewriter so that it may produce punched paper tape simultaneously with typing. Ss Se Ic RMSa

Teleregister Corp., 445 Fairfield Ave., Stamford, Conn. / Stamford 48-4291 /
Digital and analog special purpose computers. Data inventory systems for special applications: travel reservations, flight data processing, stock market quotations, etc. Magnetronic Reservisor, in use at American Airlines reservations center. Magnetronic stock quotation system in use in Toronto Stock Exchange. Ms(275) Me (1928) DIc RMSa

Underwood Corp., One Park Ave., New York 16, N.Y. / Lexington 2-7000 / General Research Lab., 56 Arbor St., Hartford 6, Conn.; and elsewhere.
Accounting machines, adding machines, typewriters. Elliott-Fisher and Sundstrand Machines. Underwood Samas punched card accounting machines and systems. Underwood electric typewriters, used in Harvard Mark II calculator. ELECOM electronic computers. SEE also Electronic Computer Division of Underwood Corporation. Ls(company 10,000; laboratory, 100) Le(1895) DIc RMSa

Union Switch and Signal Co., Division of Westinghouse Airbrake, Pittsburgh 18, and Swissvale, Pa.
Railroad signaling and control systems. Ls(4000) Le Ic RMSa

U. S. Air Force, Aeronautical Research Laboratory, System Dynamics Analysis Branch, Wright Air Development Center, Wright-Patterson Air Force Base, Dayton, Ohio / KE 7111, X28235 /
Has Oarac, and analog equipment. Ms (65) Se(1948) DAc RCGPa

U. S. Air Force, Cambridge Research Center, 230 Albany St., Cambridge 39, Mass. / University 4-4720 /
Developed the ABC (Automatic Binary Computer). Has a Computer Research Corp-102. Ms Me DIc Ga

U. S. Air Force, Inst. of Technology,

Wright-Patterson Air Force Base, Dayton, Ohio.
Electronic strategy machine, conceived by L. I. Davis. Philbrick and Reac equipment on hand. Ms(300) Se(1946) DAIc Ga

U. S. Army, Ballistic Research Laboratories, Aberdeen Proving Ground, Aberdeen, Md.
Has Bell, Edvac, Eniac, Ordvac computers and others. Developing supplementary and modernizing components. Ms Le DAc Ga

U. S. Naval Proving Ground, Computation and Ballistics Department, Dahlgren, Va. / X627 /
Has three digital computers—Harvard Aiken Relay (Mark II), Aiken Dahlgren Electronic (Mark III), and Naval Ordnance Research Calculator (NORC). Ms(110) Se(1942) Dc RCPGa

U. S. Naval Research Laboratory, Washington 25, D.C.
Making NAREC digital computer. Ls (3000) Me DASc RCGPa

U. S. Navy, Office of Naval Research, Special Devices Center, Port Washington, New York / Port Washington 7-2800/
Ls(500) Se(1943) DASMc RMCGBa

Univ. of California, Berkeley, Calif.
Constructing CALDIC, California Digital Computer. Ss(10) Se(1947) DAc RPa

University of Illinois, Urbana, Ill.
Built electronic digital computer Ordvac for Ballistic Research Laboratory, Aberdeen. Has finished computer Illiac on same design, but with faster input-output using a photoelectric reader. Dc RCPa

University of Manchester, Mathematical Laboratory, Manchester, England.
Has automatic electronic digital computer built by Ferranti Electric Ltd. This laboratory developed much of the design. Ss(8) Se(1947) Dc RPa

Univ. Mathematical Laboratory, Free School Lane, Cambridge, England.
Has EDSAC electronic digital calculator. Dc RCPa

Univ. of Michigan, Willow Run Research Center, Willow Run Airport, Ypsilanti, Mich. / Ypsilanti 5110 /
Digital computers, both special purpose and general purpose, including electronic and electromechanical analog computers; simulators. Data-processing systems, analysis and computation using Midac and Midsac; instruction in programming and numerical methods; simulation, etc. Ls(500) Se(1946) DAc RCPa

University of Sydney, Dept. of Electrical Engrg., Section of Mathematical Instruments, Sydney, New South Wales, Australia.
Analog computers. Ac Ra

Univ. of Toronto, Computation Centre, Toronto, Canada / Walnut 3-1327 /
Digital, electronic computers. Now operating: a Ferranti Electric automatic computer; punch card machines. Ss(15) Se(1947) Dc RPCa

Vaucanson, 11 rue de Surmelin, Paris 20e, France.
Calculating machines. Dc RMSa

Victor Adding Machine Co., 3900 No. Rockwell St., Chicago 18, Ill.
Adding machines. Ls(1600) Le(1918) Dc RMSa

Wallind-Pierce Corp., 1928 Pacific Coast Highway, Lomita, Calif.
Digital-to-analog, and analog-to-digital translators. Digital and analog computers, magnetic amplifiers, etc. Ss(18) Se(1951) DASc RCMSa

Wang Laboratories, 37 Hurley St., Cambridge 39, Mass. / Trowbridge 6-1925 /
Magnetic delay-line memory units. Digital signal generators. Multiple scalers. Static magnetic memory systems and other devices. Ss Se(1951) Dc RCMSa

The George Washington Univ., Logistics Research Project, 707 22nd St., Washington 7, D.C. / Sterling 3-4539 /
ONR relay computer with magnetic drum memory. Data-handling machines. ONR electronic digital computer with magnetic drum memory. Ms(50) Se (1950) Dc RCPa

Watson Scientific Computing Laboratory, 612 West 116 St., New York, N.Y. / Monument 6-9600 /
The pure science department of International Business Machines Corp. Simultaneous linear equation solver. Astronomical plate measuring machine. IBM punch card machines. Research and instruction. Constructed NORC. Ms(100) Se(1945) DAc RCPa

Wayne University, Cass Ave., Detroit 1,

Mich. / Temple 1-1450 /
Computation laboratory. 5300-word magnetic drum computer built of Burroughs pulse control equipment. Has Mass. Inst. of Technology Differential Analyzer No. 1. Acquiring digital differential analyzer and electronic analog equipment. Instruction and training. Ss(30) Se(1950) DAc Ra

Westinghouse Electric Corp., Industry Engineering Dept., East Pittsburgh, Pa.
Analog computers for: mechanical and electrical problems; regulating systems; servomechanism behavior; flow of heat, oil, or gas; other purposes. DC and AC calculating boards, ANACOM computer. Ls Le DASc RMSCPa

Wharf Engineering Labs., Fenny Compton, Warwickshire, England / Fenny Compton 30 /
Magnetic drums, recording heads, transformers. Ss(15) Se(1949) Ic RMSa

Zator Co., 79 Milk St., Boston 9, Mass. / Liberty 2-4624 /
Digital equipment and systems for coding, filing, and finding information (Zato coding systems). High-speed selectors for notched cards. Methods for use of digital computing machines to recover information. Ss Se(1947) Ic RCSa

Zeuthen & Aagaard Ltd., 6 Esplanaden, Copenhagen, Denmark / Central 3795 /
Portable adding machine (Contex); dictating machine (Rex-Recorder) with magnetic recording on plastic disc using impregnated particles and permitting more than 10,000 reuses; duplicating machines, etc. Ls Le Ic RMSa

Konrad Zuse, Kreis Hünfeld No. 69, Neukirchen, Germany
Electronic digital computers. Has made Zuse Model IV and V computers. Ss(90) Se(1949) Dc RMSa

VIII:3 ROSTER OF AUTOMATIC COMPUTING SERVICES

The purpose of this Roster is to report organizations offering automatic computing services and having at least one automatic computer, either analog or digital. Current additions and changes are published from time to time in the magazine "Computers and Automation" (see bibliography).

Each Roster entry when it is complete contains: name of the organization, its address / analog or digital computation provided / notes on equipment / any restrictions as to clients.

Some of the abbreviations are as follows:

A	analog
anal	analyzer
CPC	IBM card programmed calculator
D	digital
diff	differential
govtO	available to government agencies or contractors only
unres	unrestricted

ROSTER

Armour Research Foundation of Illinois Inst of Tech, 10 West 35 St, Chicago 16, Ill / A, D / Goodyear Electronic Differential Analyzers, Two Channel Electronic Function Generator, CPC / unres

Askania Regulator Co, 240 East Ontario St, Chicago 11, Ill / A / Philbrick / unres

Battelle Memorial Inst, 505 King Ave, Columbus 1, Ohio / A, D / diff anal, CPC, punch card / unres

Burroughs Corporation Research Center, Paoli, Pa. / D / Burroughs Laboratory Computer / unres

Cornell Computing Center, Rand Hall, Cornell University, Ithaca, N Y / D / CPC, punch card / unres

Electro-Data Corporation, 717 North Lake Ave, Pasadena 6, Calif / D / CEC 30-201, etc. / unres

Engineering Research Associates, Division of Remington Rand, 555 23rd St South, Arlington 2, Va / D / ERA 1101 / unres

Financial Publishing Co, Mathematical Tables Div, 82 Brookline Ave, Boston 15, Mass / D / CPC's, punch card / unres

The Franklin Inst Laboratories for Research and Development, 20 St and Benj Franklin Pkwy, Philadelphia 3, Pa / A / A.C. network analyzer / unres

General Electric Co, Schenectady, N Y / A / network anal AC and DC, diff anal / unres

The George Washington University Logistics Research Project, 707 22nd St, Washington, D C / D / ONR automatic relay computer / unres

Harvard Computation Laboratory, Harvard University, Cambridge 38, Mass / D / Harvard IBM Mark I, Harvard Mark IV / unres

International Business Machines Corp, 590 Madison Ave, New York, N Y, and elsewhere / D / IBM 701, 650, 604, CPC, punch card, etc / unres

Machine Statistics Co, 27 Thames St, New York 6, N Y / D / IBM 604, punch card / unres

Mass. Inst. of Technology, Office of Statistical Services, Cambridge 39, Mass / D / IBM 604, CPC, punch card / unres

Moore School of Electrical Engineering, 200 South 33 St, Phila 4, Pa / A, D / diff anal, CPC, punch card / unres

National Bureau of Standards, Applied Mathematics Laboratory, Washington, D C / D / Seac, Dyseac, punch card / govtO

National Bureau of Standards, Institute for Numerical Analysis, 405 Hilgard Ave, Los Angeles 24, Calif / D / Swac, etc / govtO

National Cash Register Company, Electronics Division, (formerly Computer Research Corporation), 3348 West El Segundo Boulevard, Hawthorne, Calif / D / Cadac 102A, etc / unres

Northrop Aircraft, Inc, Director of Computing, Hawthorne, Calif / A, D / CPC's, Maddida, Binac, punch card, etc / unres

G A Philbrick Researches, Inc, 230 Congress St, Boston 10, Mass / A / Philbrick / unres

Purdue Univ, Dept of Math, Lafayette, Ind / D / CPC, punch card / unres

Raytheon Mfg Co, Computing Services Section, Waltham, Mass / D / automatic electronic digital computer, etc /unres

J B Rea Co, Inc, 1723 Cloverfield Blvd, Santa Monica, Calif / A, D, simulation / Electronic Associates analog computer, Beckman EASE analog computer, CPC / unres

Reeves Instrument Co, 215 East 91 St, New York, N Y / A / Reac / unres

Remington Rand, Inc, 315 4th Ave, New York, N Y / D / Univac, punch card, etc/ unres

Rensselaer Polytechnic Institute, Computer Laboratory, Troy, NY / A / Reeves Electronic Analog Computer, precision magnetic tape recorders for analog computing applications / unres

Rome Air Development Center, Computer Facilities Section, Griffiss Air Force Base, Rome, N Y / A, D / Elecom 120, Bendix Digital Differential Analyzer D 12, Reeves Electronic Analog Computer, Benson-Lehner data reduction equipment, etc / govtO

Scientific Computing Service, Ltd, 23 Bedford Sq, London W C 1, England / D / — / unres

Swedish Board for Computing Machines, Drottningatan 95A, Stockholm, Sweden/ D / Bark, Besk / unres

Telecomputing Corp, 133 East Santa Anita Avenue, Burbank, Calif / A, D / IBM punch card, CPC's, automatic graph readers, digital plotters / unres

U S Air Force, Computation Research Sec, Wright Air Development Center, Wright Patterson Air Force Base, Dayton, Ohio / A, D / CPC's, Reac's, punch card / govtO

U S Army, Ballistic Research Laboratories, Aberdeen, Md / D / Ordvac, Edvac, Eniac, Bell Model V, CPC, punch card / govtO

U S Navy, Naval Proving Ground, Dahlgren, Va / D / Norc, Harvard Mark II, Harvard Mark III, punch card / govtO

University Mathematical Laboratory, Free School Lane, Cambridge, England / D / Edsac / unres

University of Michigan, Willow Run Research Center, Ypsilanti, Mich / D / Midac, etc / unres

Univ of Toronto, Computation Centre, Toronto, Ont, Canada / D / Ferranti / unres

Univ of Wisconsin, 306 North Hall, Madison 6, Wisc / A, D / Philbrick, CPC, punch card / unres

Wayne University, Computation Laboratory, Detroit 1, Mich / A, D / diff anal, Burroughs Unitized Digital Electronic Computer, etc / unres

Westinghouse Electric Corp, Industry Engineering Dept, East Pittsburgh, Pa / A, D / Anacom network anal AC and DC, punch card / unres

VIII:4 GLOSSARY OF TERMS AND EXPRESSIONS

The following is a glossary of terms and expressions used in the field of automatic computing machinery and some closely allied fields. The purpose of this glossary is to report or indicate the meanings of terms as used. In general, the entry for any expression appears in alphabetic order according to the first word of the expression. For example "excess three code" appears under "e" for "excess" instead of "c" for "code."

This glossary is reprinted with a few changes from "Computers and Automation," vol. 5, no. 1, January, 1956. In turn, that glossary has drawn to a considerable extent on previously published glossaries, as mentioned in the Acknowledgements at the beginning of this book.

For additions and changes in the nomenclature of the field, see current issues of the above magazine.

A: absolute address — Digital Computer Programming. The label assigned by the machine designer to a specific register or location in the storage.

absolute coding — Coding that uses absolute addresses.

—ac — An ending that means "automatic computer", as in Eniac, Seac, etc.

access time — Digital Computers. 1. The time interval between the instant at which the arithmetic unit calls for information from the memory unit and the instant at which the information is delivered from storage to the arithmetic unit. 2. The time interval between the instant at which the arithmetic unit starts to send information to the memory unit and the instant at which the storage of the information in the memory unit is completed. — In analog computers, the value at time t of each dependent variable represented in the problem is usually immediately accessible when the value of the independent variable is at time t, and otherwise not accessible.

accumulator — Digital Computers. 1. A unit in a digital computer where numbers are totaled, that is, accumulated. 2. A register in the arithmetic unit of a digital computer where the result of arithmetical or logical operations is first produced. — Often the accumulator stores one quantity and upon receipt of any second quantity, it forms the sum of the first and the second quantities and stores that instead. Sometimes the accumulator is able to perform other operations upon a quantity stored in its register such as sensing, shifting, complementing, etc.

accuracy — Correctness, or freedom from error. Accuracy contrasts with precision; for example, a four-place table, correctly computed, is accurate; while a six-place table containing an error is more precise but not accurate.

acoustic memory — Computers. Computer memory which uses a sonic delay line, one which employs a train of pulses in the molecules of a medium such as mercury or quartz (sound pulses).

adder — Computers. A device that can form the sum of two quantities delivered to it. Examples are: an accumulator; a differential gear assembly; etc.

address — Digital Computers. A label, name, or number identifying a register, a location, or a device where information is stored. See also: absolute address, floating address, relative address, symbolic address.

addressed memory — Digital Computers. The sections of the memory where each individual register bears an address. — In storage on magnetic tape, usually only blocks of a number of items of information have addresses, and an individual item does not have an individual address associated with it.

alphabetic coding — A system of abbreviation used in preparing information for input into a machine, such that information may be reported not only in numbers but also in letters and words. For example, Boston, New York, Philadelphia, Washington, may in alphabetic coding be reported as BS, NY, PH, WA. Some computers will not accept alphabetic coding but require all abbreviations to be numerical, in which case these places might be coded as 0, 1, 2, 3.

analog — Using physical variables, such as distance or rotation or voltage, or measurements of similar physical quantities, to represent and correspond with numerical variables that occur in a computation; contrasted with "digital".

analog computer — A computer which calculates by using physical analogs of the variables. Usually a one-to-one correspondence exists between each numerical variable occurring in the problem and a varying physical measurement in the analog computer.

and — Logic. A logical operator which has the property that if P and Q are two statements, then the statement "P AND Q" is true or false precisely according to the following table of possible combination:

P	Q	P AND Q
false	false	false
false	true	false
true	false	false
true	true	true

The AND operator is often represented by a centered dot (·), or by no sign, as in P · Q, PQ.

'and' circuit — Circuits. A pulse circuit with two input wires and one output wire, which has the property that the output wire gives a pulse if and only if both of the two input wires receive pulses. Also called a "gate" circuit.

arithmetic check — A check of a computation, making use of arithmetical properties of the computation; for example, checking the multiplication A x B by comparing it with B x A.

arithmetic operation — An operation in which numerical quantities form the elements of the calculation. Such operations include the "fundamental operations of arithmetic", which are addition, subtraction, multiplication and division.

arithmetic shift — The multiplication or division of a quantity by a power of the base of notation. For example, since 1011 represents eleven in binary notation, the result of two arithmetic shifts to the left is 101100, which represents forty-four.

arithmetic unit — Digital Computers. The section of the hardware of a computer where arithmetical and logical operations are performed on information.

asynchronous computer — Digital Computers. An automatic computer where the performance of any operation starts as a result of a signal that the previous operation has been completed; contrasted with "synchronous computer", which see.

automatic carriage — Punch Card Machines. A typewriting carriage which is automatically controlled by information and program so as to feed forms or continuous paper, space, skip, eject, tabulate, etc. It may produce any desired style of presentation of information on separate forms or on continuous paper.

automatic checking — Computers. Provision, constructed in hardware, for automatically verifying the information transmitted, manipulated or stored by any device or unit of the computer. Automatic checking is "complete" when every process in the machine is automatically checked; otherwise it is partial. The term "extent of automatic checking" means either (1) the relative proportion of machine processes which are checked, or (2) the relative proportion of machine hardware devoted to checking.

automatic computer — A computer which automatically handles long sequences of reasonable operations with information.

automatic controller — A device which controls a process by (1) automatically receiving measurements of one or more physical variables of the process, (2) automatically performing a calculation, and (3) automatically issuing suitably varied actions, such as the relative movement of a valve, so that the process is controlled as desired; for example, a flyball governor on a steam engine, or an automatic pilot.

automatic programming — Digital Computer Programming. Any technique whereby the computer itself is used to transform programming from a form that is easy for a human being to produce into a form that is efficient for the computer to carry out. Examples of automatic programming are compiling routines, interpretive routines, etc.

automation — 1. Process or result of rendering machines self-acting or self-moving; rendering automatic. 2. Theory or art or technique of making a device or a machine or an industrial process more fully automatic. 3. Making automatic the process of moving pieces of work from one machine tool to the next.

available machine time — Time that a computer has the power turned on, is not under maintenance, and is known or believed to be operating correctly.

average calculating operation — A common or typical calculating operation longer than an addition and shorter than a multiplication; often taken as the mean of nine additions and one multiplication.

B: base — Numbers. Ten in the decimal notation of numbers, two in the binary notation of numbers, eight in octal notation, and in general the radix in any scale of notation for numbers.

binary — Involving the integer two. For example, the binary number system uses two as its base of notation. A binary choice is a choice between two alternatives; a binary operation is one that combines 2 quantities.

binary cell — An element that can have one or the other of two stable states or positions and so can store a unit of information.

binary-coded decimal notation — One of many systems of writing numbers in which each decimal digit of the number is expressed by a different code written in binary digits. For example, the decimal digit zero may be represented by the code 0011, the decimal digit one may be represented by the code 0100, etc.

binary digit — A digit in the binary scale of notation. This digit may be only 0 (zero) or 1 (one). It is equivalent to an "on" condition or an "off" condition, a "yes" or a "no", etc.

binary notation — The writing of numbers in the scale of two. The first dozen numbers zero to eleven are written 0, 1, 10, 11, 100, 101, 110, 111, 1000, 1001, 1010, 1011. The positions of the digits designate powers of two; thus 1010 means 1 times two cubed or eight, 0 times two squared or four, 1 times two to the first power or two, and 0 times two to the zero power or one; this is equal to one eight plus no four's plus one two plus no ones, which is ten.

binary number — A number written in binary notation.

binary point — In a binary number, the point which marks the place between integral powers of two and fractional powers of two, analogous to the decimal point in a decimal number. Thus, 10.101 means four, one half, and one eighth.

·binary to decimal conversion—The mathematical process of converting a number written in binary notation to the equivalent number written in the ordinary decimal notation.

biquinary notation — Numbers. A scale of notation in which the base is alternately 2 and 5. For example, the number 3671 in decimal notation is 03 11 12 01 in biquinary notation; the first of each pair of digits counts 0 or 1 units of five, and the second counts 0, 1, 2, 3, or 4 units. For comparison, the same number in Roman numerals is MMMDCLXXI. Biquinary notation expresses the representation of numbers by the abacus, and by the two hands and five fingers of man; and has been used in some automatic computers.

bit — A binary digit; a smallest unit of information; a "yes" or a "no"; a single pulse in a group of pulses.

block — Digital Computers. A group of consecutive machine words considered or transferred as a unit, particularly with reference to input and output.

bootstrap — Digital Computer Programming. The coded instructions at the beginning of an input tape, together with one or two instructions inserted by switches or buttons into the computer, used to put a routine into the computer.

break-point — Digital Computer Programming. A point in a routine at which the computer may, under the control of a manually set switch, be stopped for an operator's check of the progress of the routine.

buffer — Circuits. 1. An isolating circuit used to avoid any reaction of a driven circuit upon the corresponding driving circuit. 2. A circuit having an output and a multiplicity of inputs so designed that the output is energized whenever one or more inputs are energized. Thus, a buffer performs the circuit function which is equivalent to the logical "or", which see.

buffer storage — Digital Computers. 1. Equipment linked to an input device, in which information is assembled from external storage and stored ready for transfer to internal storage. 2. Equipment linked to an output device into which information is transmitted from internal storage and held for transfer to external storage. Computation continues while transfers between buffer storage and external storage take place.

bus — Digital Computers. A path over which information is transferred, from any of several sources to any of several destinations; a channel, line, or trunk.

C: call-number — Digital Computer Programming. A set of characters identifying a subroutine, and containing information concerning parameters to be inserted in the subroutine, or information to be used in generating the subroutine, or information related to the operands.

call-word — Digital Computer Programming. A call-number which fills exactly one machine word.

capacity — Digital Computer Arithmetic. 1. The number of digits or characters which may regularly be processed in a computer, as in "the capacity is ten decimal digit numbers". 2. The upper and lower limits of the numbers which may regularly be handled in a computer, as "the capacity of the computer is + .00000 00001 to .99999 99999". Quantities which are beyond the capacity of the computer usually interrupt its operation in some way.

card — Computers. A card of constant size and shape, adapted for being punched in a pattern which has meaning. The punched holes are sensed electrically by wire brushes, mechanically by metal fingers, or photoelectrically. Also called "punch card." One of the standard punch cards (made by International Business Machines Corporation) is 7 and 3/8 inches long by 3 and 1/4 inches wide, and contains 80 columns in each of which any one of 12 positions may be punched.

card column — Punch Card Machines. One of a number of columns (45, 80, or 90) in a punch card into which information is entered by punches.

card feed — Punch Card Machines. A mechanism which moves cards one by one into a machine.

card field — Punch Card Machines. A set of card columns fixed as to number and position, into which the same item of information is regularly entered; for example, purchase order numbers of five decimal digits might be punched regularly into the card field consisting of card columns 11 to 15.

card stacker — Punch Card Machines. A mechanism that stacks cards in a pocket or bin after they have passed through a machine. Sometimes called "card hopper".

card reader — Punch Card Machines. A mechanism that causes the information in cards to be read, usually by passing them under copper wire brushes or across metal fingers.

card punch — Punch Card Machines. A mechanism which punches cards, or a machine which punches cards according to a program.

carry — Arithmetic. 1. The digit to be taken to the next higher column (and there added) when the sum of the digits in one column equals or exceeds the number base. 2. The process of transferring the carry digit to the next higher column.

cathode ray tube — Digital Computers. 1. A large electronic vacuum tube containing a screen on which information, expressed in pulses in a beam or ray of electrons from the cathode, is stored by means of the presence or absence of spots bearing electrostatic charges. The capacity usually is from 256 to 1024 spots. 2. A similar tube with screen for visual display of output in graphic form.

cell — Digital Computers. Storage for one unit of information, usually one character or one machine word. More specific terms ("column, location, block") are preferable since there is little uniformity in the use of the term "cell".

channel — 1. Digital Computers. A path along which information, particularly a series of digits or characters or units of information, may flow or be stored. For example, in the machine known as a punch card reproducer, information (in the form of punch cards) may flow in either one of two card channels which do not physically connect. 2. Magnetic Tape or Magnetic Drums. A path parallel to the edge of the tape or drum along which information may be stored by means of the presence or absence of polarized spots, singly or in sets. 3. Delay Line Memory such as a Mercury Tank. A circular path forward through the delay line memory and back through electrical circuits along which a pattern of pulses representing information may be stored.

character — Digital Computers. 1. A decimal digit 0 to 9, or a letter A to Z, either capital or lower case, or a punctuation symbol, or any other single symbol (such as appear on the keys of a typewriter) which a machine may take in, store, or put out. 2. A representation of such a symbol in a pattern of ones and zeros representing a pattern of positive and negative pulses or states.

check digit — One or more digits carried along with a machine word (i.e., a unit item of information handled by the machine), which report information about the other digits in the word in such fashion that if a single error occurs (excluding two compensating errors), the check will fail and give rise to an error alarm signal. For example, the check digit may be 0 if the sum of other digits in the word is odd, and the check digit may be 1 if the sum of other digits in the word is even.

circulating memory — Digital Computers. A device using a "delay line" which stores information in a train of pulses or waves, as a pattern of the presence or absence of such pulses, where the pattern of pulses issuing at the final end of the delay line is detected electrically, amplified, reshaped, and reinserted in the delay line at the beginning end.

clock frequency — Digital Computers. The master frequency of periodic pulses which schedules the operation of the computer.

closed subroutine — Digital Computer Programming. A subroutine with the following properties: (1) it is stored separately from the main routine; (2) at the proper point in the main routine, a jump instruction transfers control to the beginning of the subroutine; (3) at the end of the subroutine, another jump instruction transfers control back to the proper point in the main routine.

clear (verb) — Digital Computers. To replace information in a register by zero as expressed in the number system employed.

code (noun) — Computers. A system of symbols for representing information in a computer and the rules for associating them.

code (verb) — Computers. To express information, particularly problems, in language acceptable to a specific computer.

coded decimal (adjective) — Computers. A form of notation by which each decimal digit separately is converted into a pattern of binary ones and zeros. For example, in the "8-4-2-1" coded decimal notation, the number twelve is represented as 0001 0010 (for 1, 2) whereas in pure binary notation it is represented as 1100. Other coded decimal notations are known as: "5-4-2-1", "excess three", "2-4-2-1", etc.

coded decimal digit — A decimal digit which is expressed by a pattern of four or more ones and zeros.

coded program — A program which has been expressed in the code for a computer.

coder — A person who translates a sequence of instructions for an automatic computer to solve a problem into the precise codes acceptable to the machine.

coding — The list in computer code of the successive computer operations required to carry out a given routine or subroutine or solve a given problem.

coding line — A single command or instruction written usually on one line, in a code for a computer to solve a problem.

collate — To combine two sequences of items of information in any way such that the same sequence is observed in the combined sequence. For example, sequence 12, 29, 42 and sequence 23, 24, 48 may be collated into 12, 23, 24, 29, 42, 48. More generally, to combine two or more similarly ordered sets of items to produce another ordered set composed of information from the original sets. Both the number of items and the size of the individual items in the resulting set may differ from those of either of the original sets.

collator — Punch Card Machines. A machine which has two card feeds, four card pockets, and three stations at which a card may be compared or sequenced with regard to other cards, so as to determine the pocket into which it is to be placed. The machine is particularly useful for matching detail cards with master cards, for merging cards in proper sequence into a file of cards, etc.

column — 1. Writing. The place or position of a character or a digit in a word, or other unit of information. 2. Computers. One of the characters or digit positions in a positional notation representation of a unit of information. Columns are usually numbered from right to left, zero being the rightmost column if there is no decimal (or binary, or other) point, or the column immediately to the left of the point if there is one. 3. Arithmetic. A position or place in a number, such as 3876, written in a scale of notation, corresponding to a given power of the radix. The digit located in any particular column is the coefficient of the corresponding power of the radix; thus, 8 in the foregoing example is the coefficient of 10^2.

command — A pulse, signal, or set of signals initiating one step in the performance of a computer operation.

comparator — 1. Circuits. A circuit which compares two signals and supplies an indication of agreement or disagreement; or a mechanism by means of which two items of information may be compared in certain respects, and a signal given depending on whether they are equal or unequal. 2. Computers. A device for comparing two different transcriptions of the same information to verify agreement or determine disagreement.

comparison — Computers. The act of comparing and, usually, acting on the result of the comparison. The common forms are comparison of two numbers for identity, comparison of two numbers for relative magnitude, and comparison of two signs plus or minus.

compiler — Digital Computer Programming. A program-making routine, which produces a specific program for a particular problem by the following process: (1) determining the intended meaning of an element of information expressed in pseudo-code; (2) selecting or generating (i.e., calculating from parameters and skeleton instructions) the required subroutine; (3) transforming the subroutine into specific coding for the specific problem, assigning specific memory registers, etc., and entering it as an element of the problem program; (4) maintaining a record of the subroutines used and their position in the problem program; and (5) continuing to the next element of information in pseudo-code.

compiling routine — Computers. A routine by means of which a computer can itself construct the program to solve a problem by assembling, fitting together, and copying other programs stored in its library of routines. Same as "compiler", which see.

complement — Arithmetic. A quantity which is derived from a given quantity, expressed in notation to the base *n*, by one of the following rules. (a) Complement on n: subtract each digit of the given quantity from $n-1$, add unity to the rightmost digit not zero, and perform all resultant carries. For example, the twos complement of binary 11010 is 00110; the tens complement of decimal 679 is 321.(b) Complement on $n-1$; subtract each digit of the given quantity from $n-1$. For example, the ones complement of binary 11010 is 00101; the nines complement of decimal 679 is 320. The complement is frequently employed in computers to represent the negative of the given quantity.

complete operation — Computers. A calculating operation which includes (1) obtaining all the numbers entering into the operation out of the memory, (2) making the calculation, (3) putting the results back into the memory, and (4) obtaining the next instruction.

computer — 1. A machine which is able to calculate or compute, that is, which will perform sequences of reasonable operations with information, mainly arithmetical and logical operations. 2. More generally, any device which is capable of accepting information, applying definite reasonable processes to the information, and supplying the results of these processes.

computing machinery — Machinery which is able to take in and give out information, perform reasonable operations with the information, and store information.

computer code — Computers. The code

expressing the operations built into the hardware of the computer.

computer operation — Computers. The electronic, mechanical, or other physical operation of hardware in a computer resulting from an instruction to the computer.

conditional — Computers. Subject to the result of a comparison made during computation; subject to human intervention.

conditional breakpoint instruction — Digital Computer Programming. A conditional jump instruction which, if some specified switch is set, will cause the computer to stop, after which either the routine may be continued as coded or a jump to another routine may be directed.

conditional transfer of control — Digital Computers. A computer instruction which when reached in the course of a program will cause the computer either to continue with the next instruction in the original sequence or to transfer control to another stated instruction, depending on a condition regarding some property of a number or numbers which has then been determined.

contents — Digital Computers. The information stored in any part of the computer memory. The symbol "(. . .)" is often used to indicate "the contents of. . ."; for example, (m) indicates the contents of the storage location whose address is m.

control (verb) — Digital Computers. To direct the sequence of execution of the instructions to a computer.

control circuits — Digital Computers. The circuits which effect the carrying out of instructions in proper sequence.

control register — Digital Computers. The register which stores the current instruction governing the operation of the computer for a cycle.

control sequence — Digital Computers. The normal sequence of selection of computer instructions for execution. In some computers, one of the addresses in each instruction specifies the control sequence. In most other computers the sequence is consecutive except where a jump occurs.

control unit — Digital Computers. That portion of the hardware of an automatic digital computer which directs the sequence of operations, interprets the coded instructions, and initiates the proper signals to the computer circuits to execute the instructions.

converter — A machine which changes information in one kind of language acceptable to a machine into corresponding information in another kind of language acceptable to a machine. For example, a machine which takes in information expressed in punch cards and produces the same information expressed in magnetic tape, is a "converter". Often the machine possesses limited computing facilities, spoken of as "editing facilities".

copy — Digital Computers. To transfer information stored in one memory register into another memory register, leaving unchanged the information in the first register, and replacing whatever was previously stored in the second register.

counter — A mechanism which either totals digital numbers, or allows digital numbers to be increased by additions of one in any column of the number. It is also able to be reset to zero.

crippled leap-frog test — Digital Computer Programming. A variation of the leap-frog test described below, modified so that it repeats its tests from a single set of storage locations and does not "leap".

cybernetics — 1. The study of control and communication in the animal and the machine. 2. The art of the pilot or steersman. 3. The comparative study of complex information-handling machinery and the nervous systems of the higher animals including man in order to understand better the functioning of brains.

cycle (verb) — Computers. To repeat a set of operations a specified number of times including, when required, supplying necessary memory location address changes by arithmetic processes or by means of a hardware device such as a cycle-counter.

cycle (noun) — 1. A set of operations repeated as a unit. 2. Computers. The smallest period of time or complete process of action that is repeated in order. In some computers, "minor cycles" and "major cycles" are distinguished. 3. Computer Arithmetic. A shift of the digits of a number such that digits removed from one end of the word are inserted in sequence at the other end of the word, in circular fashion.

cycle criterion — Digital Computer Programming. The total number of times that a cycle is to be repeated, or the register which stores that number.

cycle index — Digital Computer Programming. The number of times a cycle has been executed; or the difference (or the negative of the difference) between that number and the number of repetitions desired.

cycle reset — Digital Computer Programming. The returning of a cycle index to its initial value.

cyclic shift — Computer Arithmetic. A shift of the digits of a number (or the characters of a word) in which digits removed from one end of the word are inserted in the same sequence at the other end of the word, in circular fashion.

D: data — Computers. Any facts or information, particularly as taken in, operated on, or put out by a computer or other machine for handling information.

data processor — A machine for handling information in a sequence of reasonable operations.

DC dump — Digital Computers. The condition resulting when direct current power is withdrawn from a computer which uses volatile storage, i.e., loss of information stored in such storage.

debug — Computers. To isolate and remove malfunctions from a computer or mistakes from a program.

decade — A group of ten; for example, a "decade counter" will count to ten in one column or place of a decimal number.

decimal digit — One of the symbols 0, 1, 2, 3, 4, 5, 6, 7, 8, 9 when used in numbering in the scale of ten. Two of these digits, 0 and 1, are of course also binary digits when used in numeration in the scale of two.

decimal notation — The writing of quantities in the scale of ten.

decimal point — In a decimal number, the point that marks the place between integral and fractional powers of ten.

decimal-to-binary conversion — Mathematical process of converting a number written in the scale of ten into the same number written in the scale of two.

decision element — Circuits. A circuit which performs a logical operation such as AND, OR, NOT, OR EXCEPT, on one, two, or several binary digits representing "yes" or "no".

delay line — Computers. A device which stores information in a train of pulses or waves, and as a pattern of the presence or absence of such waves. An example of a delay line in everyday life is an echo; the air and a reflecting wall momentarily store a train of sound waves. In a computer delay line, the medium may be mercury, the container a pipe, and the pulses issuing at the final end may be detected electrically, amplified, reshaped, and reinserted at the beginning end.

diagnostic routine — Digital Computer Programming. A specific routine designed to locate either a malfunction in the computer or a mistake in coding.

diagram — Digital Computer Programming. A schematic representation of a sequence of subroutines designed to solve a problem. It is a less detailed and less symbolic representation than a flow chart, and frequently includes descriptions in English words.

differential analyzer — An analog computer designed particularly for solving or "analyzing" many types of differential equations.

differentiator — Analog Computers. A device whose output signal is proportional to the derivative of an input signal.

digit — 1. One of the symbols 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, used in numbering in the scale of ten. 2. One of these symbols and sometimes also letters expressing integral values ranging from 0 to $n-1$ inclusive, used in a scale of numbering to the base n.

digital — Using numbers expressed in digits and in a scale of notation, in order to represent all the variables that occur in a problem.

digital computer — A computer which calculates using numbers expressed in digits and yeses and noes expressed usually in 1's and 0's, to represent all the variables that occur in a problem.

digitize — To change an analog measurement of a physical variable into a number expressed in digits in a scale of notation.

double precision — Digital Computers. Having twice as many digits as the quantities normally handled in the computer. For example, in the case of a desk calculator regularly handling ten place decimal numbers, computation with 20 place numbers by keeping track of the 10 place fragments, is "double precision" computation.

down-time — Computer Operation. Time when a computer is malfunctioning, or not operating correctly, due to machine failure.

dummy — Digital Computer Programming. An artificial address, instruction, or other unit of information inserted solely to fulfill prescribed conditions (such as word-length or block-length) without affecting operations.

dump — 1. Computer Operation. To withdraw all power accidentally or intentionally. 2. Digital Computer Programming. To transfer all or part of the contents of one section of computer memory into another section.

dump check — A check which usually consists of adding all digits during dumping, and verifying the sum when retransferring.

duplication check — A check which requires that the results of two independent performances (either concurrently on duplicate equipment or at a later time on the same equipment) of the same operation be identical.

dynamic storage — Storage such that information at a certain position is changing over time and so is not always available instantly; for example, acoustic delay line storage or magnetic drum storage.

dynamic subroutine — Digital Computer Programming. A subroutine which involves parameters, such as decimal point position or item size, from which a relatively coded subroutine is derived. The computer itself is expected to adjust or generate the subroutine according to the parametric values chosen.

E: edit — Digital Computer Programming. To arrange or rearrange information for the output unit to print. Editing may involve the deletion of unwanted data, the selection of pertinent data, the insertion of invariant symbols such as page numbers and typewriter characters, and the application of standard processes such as zero-suppression.

education of a computer — Computers. Preparing and assembling programs for a computer so that the computer can itself put together many programs for many purposes. This greatly reduces the time required from human programmers to program the computer.

electric typewriter — A typewriter having an electric motor and the property that almost all the operations of the machine after the keys are touched by human fingers are performed by electric power instead of the power of human fingers and hands.

electronic (as contrasted with "electric") — In general, dealing with flows of small numbers of electrons in a vacuum, as contrasted with flows of large numbers of electrons along wire conductors. Exceptions: The term "electronic" also includes flows of electrons in semiconducting devices such as transistors and diodes, and also some cases of large flows of electrons in vacuums.

electronic calculating punch — Punch Card Machines. A punch card machine which, in each fraction of a second reads a punch card passing through the machine, performs a number of sequential arithmetical and logical operations electronically at high speed, and punches a result on the punch card.

electrostatic storage — Storage of information in the form of the presence or absence of spots bearing electrostatic charges. See "cathode ray tube"

equation solver — A computing device, often analog, which is designed to solve systems of linear simultaneous (nondifferential) equations or find the roots of polynomials, or both.

equivalent binary digits – Number of binary digits equivalent to a given number of decimal digits or other characters. When a decimal number is converted into a binary number, the number of binary digits necessary is in general equal to about 3 1/3 times the number of decimal digits. In coded decimal notation, the number of binary digits necessary is ordinarily 4 times the number of decimal digits.

erasable storage – Storage media which can be erased and reused; for example, magnetic tapes.

erase – Digital Computers. 1. To remove information from storage and leave the space available for recording new information. 2. To replace all the binary digits in a storage device by binary zeros. In a binary computer, erasing is equivalent to clearing, while in a coded decimal computer where the pulse code for decimal zero may contain binary ones, clearing leaves decimal zero while erasing leaves all-zero pulse codes.

error – The amount of loss of precision in a quantity; the difference between an accurate quantity and its calculated approximation. Errors occur in numerical methods; mistakes occur in programs, coding, data transcription, and operating; malfunctions occur in computers.

excess-three code – A coded decimal notation for decimal digits which represents each decimal digit as the corresponding binary number plus three. For example, the decimal digits 0, 1, 8, 9, are represented as 0011, 0100, 1011, 1100, respectively. As may be seen, in this notation, the nines complement of the decimal digit is equal to the ones complement of the corresponding four binary digits.

exchange – Digital Computer Programming. To interchange the contents of two storage devices or locations.

executive routine – Digital Computer Programming. A routine designed to process and control other routines.

external memory – Digital Computers. Materials separate from the computer itself but holding information stored in language acceptable to the machine, as for example, recorded magnetic tape in a closet, or punch cards in filing cabinets.

extract – Computers. 1. To obtain certa digits from a machine word as may b specified. For example, if the ten dig number 0000011100 is stored in a mac ine register, the computer can be instructed to "extract" the eighth dig from the left (in this case a one) an correspondingly perform a certain ac tion. 2. Digital Computers. To repla the contents of specific columns of on machine word by the contents of the corresponding columns of another machine word, depending on the instruction. 3. To remove from a set c items of information all those items that meet some arbitrary condition.

F: feedback – The returning of a fraction of the output of a machine, system, or process to the input, to which the fraction is added or subtracted. If increase of input is associated with increase of output, subtracting the returned fraction (negative feedback) results in self-correction or control of the process while adding it (positive feedback) results in a runaway or out-of-cont process.

field – 1. Punch Card Machine. A set of one or more columns in each of number of punch cards which is re larly used to report a standard ite information. For example, if colum 16 to 19 are regularly used to repo weekly rate of pay, then these colu would constitute a field. 2. Digital Computers. A set of one or more c acters (not necessarily all lying i same word) which is treated as a wh a unit of information.

fixed-cycle operation–Digital Compu Organization of a computer where fixed time is allocated to operatio although they may actually take l time than is allocated. This is the type of operation of a "synchrono computer.

fixed-point calculations – Digital Co ters. Calculation using or assumi fixed or constant location of the d mal point or the binary point in ea number.

fixed-point representation — Arithmetic. An arithmetical notation in which all numerical quantities are expressed by the same specified number of digits, with the point implicitly located at the same specified position.

flip-flop — Circuits. 1. An electronic circuit having two stable states, two input lines, and two corresponding output lines such that a signal exists on either one of the output lines if and only if the last pulse received by the flip-flop is on the corresponding input line. 2. An electronic circuit having two stable states, one input line, and one output line, such that as each successive pulse is received on the input line, the voltage on the output line changes, if it is low, to high, and, if it is high, to low.

floating-point calculation — Computers. Calculation taking into account varying location of the decimal point (if base 10) or binary point (if base 2), and consisting of writing each number by specifying separately its sign, its coefficient, and its exponent affecting the base. For example, in floating-point calculation, the decimal number —638,020,000 might be reported as —,6.3802,8, since it is equal to -6.3802×10^8.

flow chart — Digital Computer Programming. A graphical representation of a sequence of programming operations, using symbols to represent operations such as compute, substitute, compare, jump, copy, read, write, etc. A flow chart is a more detailed representation than a diagram, which see.

force (verb) — Digital Computer Programming. To intervene.

four-address (adjective) — Digital Computer Programming. Having the property that each complete instruction specifies the operation and the addresses of four registers. Usually each instruction contains the addresses of three operands (i.e., the numbers being operated with), the operation, and the address of the next order.

function switch — Circuits. A network or circuit having a number of inputs and outputs and so connected that signals representing information expressed in a certain code, when applied to the inputs, cause output signals to appear which are a function of the input information.

function table — 1. Mathematics. A table of the values for a mathematical function. 2. Computers. A hardware device or a program which translates from one representation of information to another representation.

G: gate — Circuits. An electronic circuit with two inputs and one output, which has the property that a pulse goes out on the output line if and only if some specified combination of pulses occurs on the two input lines. The combination may be the presence of pulses on both input lines, which is called an "and" gate, or the presence of a pulse on one line and the absence of a pulse on the other line, which is called an "except" gate or inhibitory gate.

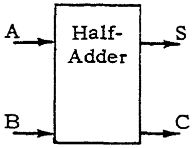
general routine — Digital Computer Programming. A routine expressed in computer coding designed to solve a class of problems, specializing to a specific problem when appropriate parametric values are supplied.

generate — Digital Computer Programming. To produce coding by assembling and modifying primitive elements; similar to generation of a line by a point, a plane by a line, etc.

generator — Digital Computer Programming. A computer program which generates coding.

H: half-adder — Circuits. A circuit having two output channels for binary signals (either zero or one) in which the output signals are related to the input signals according to the following table:

Input		Output	
A	B	C	S
0	0	0	0
0	1	0	1
1	0	0	1
1	1	1	0



This circuit expresses in hardware a part of the functions necessary for binary addition. The letter S stands for "sum without carry"; the letter C stands for "carry". With two half-adders, and another circuit properly transferring the carry from one column to the next column, a circuit which will perform binary addition can be constructed.

hardware — Computers. The mechanical, magnetic, electrical, and electronic devices from which a computer is constructed.

head — Computers. Same as "magnetic head", a small electromagnet used for reading, recording or erasing polarized spots on a magnetic surface.

hold — Computers. To retain the information contained in one storage device after copying it into a second storage device. Opposed to "clear".

holding beam — Computer Circuits. A diffuse beam of electrons for regenerating the charges stored on the dielectric surface of an electrostatic memory tube or cathode ray storage tube.

I: ignore (noun) — Output Devices. A typewriter character indicating that no action whatsoever be taken. In the system of coding punched in Teletype or Flexowriter paper tape, the character "all holes punched" is an ignore.

infinity — Computers. Any number larger than the maximum number that the computer is able to store in any register. When such a number is calculated, the computer usually stops and signals an alarm indicating an overflow.

information — 1. A set of marks or an arrangement of hardware that has meaning or that designates one out of a finite number of alternatives. 2. Any facts or data.

information word — Computers. 1. Machine word. 2. The information content of a machine word. A machine word often includes the separating space between it and the following (or preceding) word.

inherited error — Machine Computation. The error in the initial values, especially the error accumulated from the previous steps in a step-by-step integration.

input — Computers. Information transferred from secondary or external storage into the internal storage of the computer.

input block — Computers. A section the internal storage reserved for ceiving and processing input data.

input equipment — Computers. The equipment used for taking information into a computer.

input unit — Computers. The unit which takes into the computer information from outside the computer.

instruction — Computers. A machine word or a set of characters in machine language which directs the computer to take a certain action. More precisely, a set of characters which defines an operation together with one or more addresses (or no address) and which, as a unit, causes the computer to operate accordingly on the indicated quantities. Note: The term "instruction" is preferred by many to the terms "command" and "order"; "command" is reserved for electronic signals; "order" is reserved for uses in the meaning "sequence", as in "the order of the characters".

instruction code — Digital Computer Programming. The system of symbols, names, and definitions of all the instructions that are directly intelligible to a given computer or a given executive routine.

integrator — Analog Computers. A device whose varying output is proportional to the integral of a varying input magnitude.

interlace — Computers. To assign successive memory location numbers to physically separated memory locations on a magnetic drum, for example, in such a way that access time to successive memory locations is greatly reduced.

internal memory — Computers. The total memory or storage which is accessible automatically to the computer without human intervention. This equipment is an integral physical part of the computer and is directly controlled by the computer.

internal storage — Computers. Same as internal memory, which see.

interpreter — Digital Computer Programming. An executive routine which, as the computation progresses, translates a stored program expressed in some machine-like pseudo-code into machine code and performs the indicated operations, by means of subroutines, as they are translated. An interpreter is essentially a closed subroutine which operates successively on an indefinitely long sequence of program parameters (the pseudo-instructions and operands). It may usually be entered as a closed subroutine and left by a pseudo-code exit instruction.

interpreter code — A code acceptable to an "interpreter", which see.

interpretive routine — Same as "interpreter", which see.

item — 1. A separate piece of information; a separate particular. 2. Digital Computer Programming. A group of fields reporting information about a person or object. An example of an item is a punch card punched with employee's name in columns 1 to 12, employee number in columns 13 to 15, weekly rate of pay in columns 16 to 19, and other standard information about the employee in other columns.

J: jump — Digital Computer Programming. An instruction or signal which, conditionally or unconditionally, specifies the location of the next instruction and directs the computer to that instruction. A jump is used to alter the normal sequence in the control of the computer. Under certain special conditions, a jump may be caused by the operator's throwing a switch. See "transfer instruction".

K: key — Digital Computer Programming. A set of characters, forming a field, used to identify an item.

L: latency — Digital Computer Programming. Delay while waiting for information called for from the memory to be delivered to the arithmetical unit. More specifically, in a serial storage system, latency is the access time minus the word time. For example, latency is the time spent waiting for the desired memory location to arrive under the heads on a magnetic drum.

leapfrog test — Computer Operation. A program to test the internal operation of a computer, characterized by the property that it performs a series of arithmetical or logical operations on one section of memory locations, then transfers itself to another section, checks to see that the transfer is correct, and then begins the series of operations over again. Eventually the checking program will have occupied every possible position in the memory and will begin again. The term "leapfrog" comes from the indicated jump in the position of the checking routine as seen on a monitoring cathode ray tube when it transfers itself.

library — Digital Computer Programming. A collection of standard and fully tested programs, routines, and subroutines, by means of which many types of problems and parts of problems can be solved.

line-a-time printing — Printing of a whole line of characters at one time, usually by means of one typebar (bearing all characters) for each character space in the line.

location — Digital Computers. A storage position in the main internal storage or memory, storing one computer word; a storage register.

logic — Computers. In the phrase "logic of the computer", same as "logical design", which see.

logical comparison — Logic. The operation of comparing A and B; the result is 1 or yes if A is the same as B and 0 or no if A is not the same as B (or vice versa).

logical design — Computers. Design that deals with the logical and mathematical interrelationships that must be implemented by the hardware.

logical operations — Computers. The operations of comparing, selecting, making references, matching, sorting, merging, etc., where in essence ones and zeros corresponding to yeses and noes constitute the elements (yes-or-no quantities) being operated on.

loop — Digital Computer Programming. Repetition of a group of instructions in a routine.

M: machine cycle — Computers. The smallest period of time or complete process of action that repeats itself in order. In some computers, "minor cycles" and "major cycles" are distinguished.

machine language — Computers. Information in the physical form which a computer can handle. For example, punched paper tape is machine language, while printed characters on paper are not usually machine language.

machine word — Digital Computers. A unit of information of a standard number of characters, which a machine regularly handles in each transfer. For example, a machine may regularly handle numbers or instructions in units of 36 binary digits: this is then the "machine word". See also information word.

magnetic core — Computers. A form of storage where information is represented as the polarization north-south or south-north of a wire-wound magnetically permeable core, which may be straight, doughnut-shaped, etc.

magnetic drum — Computers. A rapidly rotating cylinder, the surface of which is coated with a magnetic material on which information may be stored as small polarized spots.

magnetic head — Computers. A small electromagnet used for reading, recording, or erasing polarized spots on a magnetic surface.

magnetic memory — Computers. Any portion of the memory which makes use for storage of the magnetic properties of materials.

magnetic tape — Tape made of paper, metal or plastic, coated or impregnated with magnetic material, on which polarized spots representing information may be stored.

magnetic wire — Wire made of magnetic material on which polarized spots representing information may be stored.

major cycle — Computers. In a memory device which provides access to storage positions one after another, the time interval between successive appearances of the same storage position. In other words, this is the time for one rotation of a magnetic drum or one recirculation of pulses in a delay line. It is an integral number of minor cycles.

malfunction — Computers. A failure in the operation of the hardware of a computer.

marginal checking — Computer Circuits. A system of designing electronic circuits in a computer so that certain parameters of the circuits may be varied, and the circuits tested to determine if they continue to operate satisfactorily. For example, the voltage of the heaters of the tubes, ordinarily established at 6.3 volts, may be lowered to 5 or 4.7 volts; or the operating frequency of computer cycles may be increased; or the screen voltage of the cathode ray tubes may be lowered; etc.

master clock — Computers. The primary source of timing signals.

mathematical check — A check making use of mathematical identities or other properties. For example, multiplication may be verified by the mathematical check that A multiplied by B is the same as B multiplied by A, the two multiplications being performed at different times and compared with each other. Frequently a small degree of discrepancy is acceptable; this is referred to as the tolerance.

mathematical logic — Exact reasoning about non-numerical relations using symbols that are efficient in calculation. Also called "symbolic logic".

mercury memory — Digital Computers. Delay lines using mercury as the medium for storage of a circulating train of waves or pulses.

memory — Computers. 1. The units which store information in the form of the arrangement of hardware or equipment in one way or another. Same as "storage". 2. Any device into which information can be introduced and then extracted at a later time.

memory capacity — The amount of information which a memory unit can store. It is often measured in the number of decimal digits or the number of binary digits which the memory unit can store. Other measures of memory capacity have also been defined.

mercury tank — A container of mercury holding one or more delay lines storing information.

merge — To produce a single sequence of items, ordered according to some rule (i.e., arranged in some orderly sequence), from two or more sequences previously ordered according to the same rule, without changing the items in size, structure, or total number. Merging is a special case of collating.

message — A group of words, variable in length, transported as a unit.

microsecond — A millionth of a second.

millisecond — A thousandth of a second.

minimum access programming — Digital Computer Programming. Programming in such a way that minimum waiting time is required to obtain information out of the memory. Also called "minimum latency programming", or "forced coding".

minimum access routine — Digital Computer Programming. In a computer with a serial memory, a routine coded with judicious arrangement of data and instructions in such a way that actual waiting time for information from the memory is much less than the expected random access waiting time.

minimum latency programming — Same as "minimum access programming", which see.

minimum latency routine—Same as "minimum access routine", which see.

minor cycle — Digital Computers. In a digital computer using serial transmission, the time required for the transmission of one machine word, including the space between words.

mistake — Computers. A human error which results in an incorrect instruction in a program or in coding, an incorrect element of information, or an incorrect manual operation.

modifier—Digital Computer Programming. A quantity, sometimes the cycle index, used to alter the address of an operand.

modify — Digital Computer Programming. 1. To alter in an instruction the address of the operand. 2. To alter a subroutine according to a defined parameter.

modulo *n* check — Computers. A form of check digits, such that the number of ones in each number A operated with is compared with a check number B carried along with A equal to the remainder of A when divided by *n*. For example, in a "modulo 4 check", the check numbers will be 0, 1, 2, or 3, and the remainder of A when divided by 4 must equal the reported check number B, or else an error has occurred.

N: non-erasable storage — Storage media which cannot be erased and reused, such as punched paper tapes and punched cards.

non-volatile storage — Storage media which retain information in the absence of power, such as magnetic tapes, drums, or cores.

notation — Arithmetic. A manner of representing numbers. If quantities are written in the scale of notation *n*, then the successive positions of the digits report the powers of *n*. Thus 378 in the scale of 10 or decimal notation, means 3 hundreds, 7 tens, and 8. 1101 in the scale of 2, or binary notation, means 1 eight, 1 four, no twos, and 1 one. 764 in the scale of 8, or octal notation, means 7 sixty fours, plus 6 eights, plus 4.

numeric coding — A system of coding or abbreviation in the preparation of machine language such that all information is reported in numbers. For example, places such as Boston, New York, Philadelphia, Washington, etc., may be reported as decimal digits 0, 1, 2, 3...., whereas in "alphabetic coding" alphabetic abbreviations BO, NY, PH, WA,...would be acceptable to the machine.

O: octal digit — One of the symbols 0, 1, 2, 3, 4, 5, 6, 7 when used as a digit in numbering in the scale of eight.

octal notation — Notation of numbers in the scale of eight. For example, the number 217 in this scale means 2 times 8 squared (2 x 64 = 128), plus 1 times 8, plus 7, which equals 143 in decimal notation. The number 217 in octal is equal to 010,001,111 in binary, each octal digit being changed directly into its binary equivalent. The octal notation is rather convenient in dealing with binary machines because octal numbers are easier for human beings to read than binary numbers, and yet the conversion is immediate.

odd-even check — Use of a digit carried along as a check which is 1 if the total number of ones in the machine word is even, and which is 0 if the total number of ones in the machine word is odd, or vice versa.

one-address (adjective) — Digital Computer Programming. Having the property that each complete instruction includes an operation and specifies the location of only one register in the memory. Also called "single-address".

on-line data reduction — Reduction of data that is just as fast as the data flows into the reduction process.

open subroutine — Digital Computer Programming. A subroutine inserted directly into a linear sequence of instructions, not entered by a jump. Such a subroutine must be recopied at each point that it is needed in a routine.

operand — Computers. Any one of the quantities entering into or arising from an operation. An operand may be an argument, a result, a parameter, or an indication of the location of the next instruction.

operating ratio — Computer Operation. The ratio obtained by dividing (1) the total number of hours of correct machine operation (including time when the program is incorrect through human mistakes) by (2) the total number of hours of scheduled computer operation including preventive maintenance. For example, if the computer is scheduled for three shifts totaling 120 hours in a week, and if "preventive maintenance" takes 12 hours, and "unscheduled down-time" amounts to 3 hours, then the "operating ratio" is 87½%.

operation code — Digital Computer Programming. That part of an instruction which designates the operation of arithmetic, logic, or transfer to be performed.

operation number—Digital Computer Programming. A number indicating the position of an operation or its equivalent subroutine in the sequence forming a program. When a program is stated in pseudo-code, each step must sometimes be assigned an operation number.

operator — Computers. The person who actually operates the computer, puts problems on, presses the start button, etc.

optimum programming — Programming which is the best from some point of view. See "minimum access programming".

"or" circuit — Circuits. A circuit which has two input lines and one output line, and which has the property that whenever a pulse is present on one or both of the input lines, a pulse is provided on the output line.

order — 1. Sequence. 2. Instruction. —Because of this possible confusion, the word "order" with the meaning "instruction" is avoided by many computer people.

output — Computers. 1. Information transferred from the internal storage of a computer to secondary or external storage. 2. Information transferred to any device outside of the computer.

output block — Digital Computers. A segment of the internal storage reserved for receiving data to be transferred out.

output equipment — Computers. The equipment used for transferring information out of a computer.

output unit — Computers. The unit which delivers information outside the computer in acceptable language.

overflow — Computers. In a counter or register, the production of a number which is beyond the capacity of the counter. For example, adding two numbers, each within the capacity of the registers holding them, may result in a sum beyond the capacity of the register that is to hold the sum: overflow.

P: pack — Digital Computer Programming. To combine several different brief fields of information into one machine word. For example, the fields of an employee's pay number, weekly pay rate, and tax exemptions may be stored together in one word, each of these fields being assigned a different set of digit columns.

parallel operation — Computers. The flow of information through the computer or any part of it using two or more lines or channels simultaneously.

parallel storage — Computers. Storage in which all bits, or characters, or words are essentially equally available in space, without time being one of the coordinates. Parallel storage contrasts with serial storage. When words are in parallel, the storage is said to be parallel by words; when characters within words are dealt with simultaneously, not one after the other, the storage is parallel by characters.

parameter — Digital Computer Programming. In a subroutine, a quantity which may be given different values when the subroutine is used in different parts of one main routine, but which usually remains unchanged throughout any one such use. To use a subroutine successfully in many different programs requires that the subroutine be adaptable by changing its parameters.

parity check — Use of a digit (called the "parity digit") carried along as a check which is 1 if the total number of ones in the machine word is odd, and 0 if the total number of ones in the machine word is even. See "odd-even check".

patch — Digital Computer Programming. A section of coding inserted into a routine (usually by explicitly transferring control from the routine to the patch and back again) to correct a mistake or alter the routine.

permanent memory — Computers. Storage of information which remains intact when the power is turned off; for example, storage on a magnetic drum.

plotting board — Computers. An output unit which plots the curves of one or more variables as a function of one or more other variables.

plugboard — Punch Card Machines. A removable board holding many hundreds of electric terminals into which short connecting wire cords may be plugged in patterns varying for different programs for the machine. To change the program, one wired-up plugboard is removed and another wired-up plugboard is inserted. A plugboard is equivalent to a program tape which presents all instructions to the machine at one time. It relies on X-punches and other signals in the punch cards passing through the machine to cause different selections of instructions in different cases.

plug-in-unit — A subassembly of tubes, resistors, condensers, diodes, etc., wired together, which is of a standard type and which as a whole can be plugged in or pulled out easily.

point — Arithmetic. In a scale of notation, the position designated with a dot that marks the separation between the integral and fractional parts of the number. Called "decimal point" in the scale of 10 and "binary point" in the scale of 2.

post mortem (noun) — Digital Computer Programming. A diagnostic routine which either automatically or when called for, prints out information concerning the contents of all or a specified part of the registers of the computer, after a problem tape has "died" on the computer. The purpose of a post mortem tape is to assist in the location of an error in coding the problem or in machine function.

precision — Computation. The degree of exactness with which a quantity is stated, as contrasted with "accuracy", which is the degree of exactness with which a quantity is known or observed. The number of significant figures measures the precision of a number. For example, in "computer power required is 55.7843 kilowatts," the number is precise to six figures, but its accuracy certainly is much less.

prestore — Digital Computer Programming. 1. To set an initial value for the address of an operand or a cycle index. 2. To store a quantity in an available or convenient location before it is required in a routine.

preventive maintenance — Maintenance of a system which aims to prevent failures ahead of time rather than eliminate failures which have occurred.

printer — Computers. An output mechanism which prints or typewrites characters.

program (noun) — Computers. 1. A precise sequence of coded instructions for a digital computer to solve a problem. Note: For this meaning, the term "routine" is preferred by some people. 2. A plan for the solution of a problem. A complete program includes plans for the transcription of data, coding for the computer, and plans for the effective use of the results.

program (verb) — To make a program.

program parameter — Digital Computer Programming. A parameter incorporated into a subroutine during computation. A program parameter frequently comprises a word stored relative to either the subroutine or the entry point and dealt with by the subroutine during each reference. It may be altered by the routine. It may vary depending on point of entry.

program register — Digital Computers. The register in the control unit of the computer which stores the current instruction of the program and thereby completely controls the operation of the computer during the cycle of execution of that instruction. Same as "control register". Also called "program counter".

programmed checking—Computers. A system of checking whereby (1) before running any problem P a sample problem of the same type with known answer is run, and (2) mathematical or logical checks of operations, such as comparing A × B with B × A, are included in the program for P, and (3) reliance is placed on a very high probability of correctness rather than built-in error-detection circuits.

programmer — A person who prepares sequences of instructions for a computer, without necessarily converting them into the detailed codes.

program-sensitive error — Computers. An error arising from unforeseen behavior of some circuits, discovered when a comparatively unusual combination of program steps occurs.

program step — Computers. A step in a program, usually one instruction.

program tape — Computers. The tape which contains the sequence of instructions to the computer for solving a problem.

pseudo-code — Digital Computer Programming. An arbitrary code, independent of the hardware of a computer, which must be translated into computer code if it is to direct the computer.

pseudo-random (adjective) — Computation. Having the property of being produced by a definite calculation process, but at the same time satisfying one or more of the standard tests for statistical randomness.

pulse — Circuits. In general, a sharp difference between the normal level of some medium corresponding to the average height of a wave and a high or low level of that medium corresponding to the crest or trough of a narrow wave; often, a sharp voltage change.

pulse code — A set of pulses to which a particular meaning has been assigned; the binary representations of a character.

punch card — Computers. A card of constant size and shape, suitable for punching in a pattern that has meaning, and for being handled mechanically. The punched holes are usually sensed electrically by wire brushes or mechanically by metal fingers.

punch card machinery — Machinery which operates with punch cards.

punched tape — Paper tape punched in a pattern of holes so as to convey information.

punch position — In the case of 80-column punch cards, the position of a punch in a row on the card, denoting a decimal digit 0 to 9, or what are called an "X punch" (row 11), or a "Y punch" (row 12).

Q: quantity — A positive or negative real number in the mathematical sense. Note: The term "quantity" is preferred by some computer people for referring to numeric data; the term "number" is preferred in the sense of integer or natural number, as in "the number of digits".

R: random access — Computers. Access to the memory or storage under conditions where the next register from which information is to be obtained is chosen at random. For example, access to names in the telephone book is "random access"; the next name that anyone is going to look up in the book may be almost anywhere in the book with roughly equal probability.

random access programming — Programming a problem for a computer without regard to the time for access to the information in the registers called for in the program. Contrasted with "minimum access programming".

random number — A number formed by a

set of digits selected from a random sequence of digits. A sequence of digits is random when it is constructed by a process under which each successive digit is equally likely to be any of the n digits to the base n.

rapid memory — Computers. The section of the whole memory from which information may be obtained the most rapidly.

read — Computers. 1. To copy, usually from one form of storage to another, particularly from external or secondary storage to internal storage. 2. To sense the meaning recorded in arrangements of hardware.

read-around-ratio — Digital Computers. In cathode-ray-tube storage, the number of times that information can be recorded or read or erased successively as an electrostatic charge on a single spot in the array, before the charge on surrounding spots in the array must be restored if not to be lost. This number is referred to also as the "read-around".

real time — In solving a problem, a speed sufficient to give an answer in the actual time during which the problem must be solved. For example, in the case of a human being driving a motor car: at 30 miles an hour he can regularly solve nearly all his problems in real time; and at 100 miles an hour he will regularly fail to solve some of his problems in real time.

real time operation — Computer Operation. Solving problems in real time. More precisely, processing data in time with a physical process so that the results of the data-processing are useful in guiding the physical operation.

red-tape operations — Digital Computer Programming. Computer operations called for by a program which do not directly contribute to solving the problem; namely, arithmetical, logical, and transfer operations used in modifying the address section of other instructions, in counting cycles, in rearranging data, etc.

redundant check — Computers. A check which uses extra digits in machine words, but not complete duplication, to help detect malfunctions and mistakes.

reel — A spool of tape, generally magnetic tape.

reference record — Digital Computer Programming. An output of a compiler that lists the operations and their position in the final specific routine, and contains information describing the segmentation and storage allocation of the routine.

regenerate — Digital Computers. In the operation of electrostatic storage, to restore information currently held in a cell on the cathode ray tube screen in order to counteract fading and disturbances.

register — Computers. The hardware for storing one machine word.

relative address — Digital Computer Programming. A label used to identify the position of a memory location in a routine or subroutine. Relative addresses are translated into absolute addresses by adding some specific "reference" address, usually the address at which the first word of the routine is stored. For example, if a relative address instruction specifies an address n and the address of the first word of the routine is k, then the absolute address of the memory location is $n+k$.

relative coding — Digital Computer Programming. Coding in which all addresses refer to an arbitrarily selected position, or in which all addresses are represented symbolically.

repetition rate — Computers. The fastest rate of electronic pulses usually used in the circuits of the machine.

reproducer — Punch Card Machines. A punch card machine that punches cards to agree as may be specified with other cards; a "copying" machine.

rerun — Digital Computer Programming. To run a program or a portion of it over again on the computer.

rerun point — Digital Computer Programming. One of a set of planned-for points in a program such that if an error is detected in between two such points, to rerun the problem it is only necessary to go back to the last rerun point, instead of returning to the start of the problem. Rerun points are often three to five minutes apart so that very little computer time is required for a rerun. All information pertinent to a rerun is available in standby registers during the whole time from one rerun point to the next.

rerun routine — Digital Computer Programming. A routine designed to be used in the wake of a malfunction or a mistake to reconstitute a routine from the last previous rerun point.

reset — To return a register to zero or to a specified initial condition.

resolver — Analog Computers. A device for resolving a vector into two mutually perpendicular components.

restore — Computers. To return a cycle index, a variable address, or other computer word to its initial value. See also "reset".

rewind — Computers. To return a magnetic tape to its beginning.

roll out (verb) — Computers. To read out of a register or counter by the following process: add to the digits in each column simultaneously; do this 10 times (for decimal numbers); when the result in each column changes from 9 to 0, issue a signal.

rollback — Digital Computer Programming. Same as "rerun", which see.

round off — Computation. To change a more precise quantity to a less precise one, usually choosing the nearest less precise one; see "precision".

rounding error — Computation. The error resulting from dropping certain less significant digits of a quantity, and applying some adjustment to the more significant digits retained. Also called "round-off error". A common round-off rule is to take the quantity to the nearest digit. Thus pi, 3.14159265..., rounded to four decimals is 3.1416. Note: Alston S. Householder suggests the following terms: "initial errors", "generated errors", "propagated errors" and "residual errors". If x is the true value of the argument, and x^* the quantity used in computation, then assuming one wishes $f(x)$, $x - x^*$ is the initial error, $f(x) - f(x^*)$ the propagated error. If f_a is the Taylor, or other, approximation utilized, then $f(x^*) - f_a(x^*)$ is the residual error. If f^* is the actual result, then $f_a - f^*$ is the generated error, and this is what builds up as a result of rounding.

routine — Digital Computers. 1. A sequence of operations which a digital computer may perform. 2. The sequence of instructions determining these operations. 3. A set of coded instructions arranged in proper sequence to direct the computer to perform a desired operation or series of operations. See also "subroutine" and "program".

run (noun) — Computers. 1. One performance of a program on a computer. 2. Performance of one routine, or several routines during which the human operator does not have to do anything.

S: scale (verb) — Computation. To change the scale (that is, the units) in which a variable is expressed so as to bring it within the capacity of the machine or program at hand.

scale factor — Computation. One or more factors used to multiply or divide quantities occurring in a problem and convert them into a desired range, such as the range from plus one to minus one.

screen — Circuits. In an electrostatic storage tube, the surface where electrostatic charges are stored. In a pentode, one of the grids.

secondary storage — Computers. Storage that is not an integral part of the computer but directly linked to and controlled by the computer; for example, magnetic tapes.

segment (noun) — Digital Computer Programming. In a routine too long to fit into internal storage, a part short enough to be stored entirely in the internal storage yet containing the coding necessary to call in and jump automatically to other segments. Routines which exceed internal storage capacity may be automatically divided into segments by a compiler.

segment (verb) — To make segments.

selectron — Digital Computers. A type of electronic tube for computer memory which stores 256 binary digits for very rapid selection and access.

sense (verb) — Computers. 1. To determine the arrangement of some element of hardware, especially a manually-set switch. 2. To read holes punched in paper.

sentinel — Digital Computer Programming. A symbol marking the beginning or the end of some piece of information such as a field, item, block, tape, etc., a tag.

select — Logic. To take A if the report on a certain condition is yes, and take B if the report is no.

selector — Punch Card Machines. A mechanism which reports a condition and causes a card or an operation to be selected accordingly.

sequence (verb) — Logic. To select A if A is greater than or equal to B, and select B if A is less than B, or some variation of this operation.

sequence checking routine — A checking routine which checks on every instruction executed, printing certain data. It may be designed to print out the coded instruction with addresses, and the contents of each of several registers for each instruction as it is executed. Or it may be designed to print out only selected data, such as transfer instructions when they occur, and the quantity actually transferred. Many variations are possible. A good flexible sequence checking routine will provide for several variations in itself.

sequence-control tape — Program tape. (obsolescent term).

sequential control — Computers. The manner of control of a computer in which instructions to it are set up in a sequence and are fed in that sequence to the computer during the solution of a problem.

sequence — Punch Card Machines. A mechanism which will put items of information in sequence. It will determine if A is greater than, equal to, or less than B, and will accordingly route cards containing A and B into a pocket at different times.

serial — Computers. Handled one after the other in a single piece of equipment.

serial operation — Computers. The flow of information through the computer or in any part of it using only one line or channel at a time. Contrasted with "parallel operation."

serial storage — Computers. Storage in which time is one of the coordinates used to locate any given bit, character, or (especially) word. Storage in which words, within given groups of several words, appear one after the other in time sequence, and in which access time therefore includes a variable latency or waiting time of zero to many word-times, is said to be serial by word. Storage in which the individual bits comprising a word appear in time sequence is serial by bit. Storage for coded-decimal or other non-binary numbers in which the characters appear in time sequence is serial by character; for example, magnetic drums are usually serial by word but may be serial by bit, or parallel by bit, or serial by character and parallel by bit, etc.

serial transfer — Computers. A system of data transfer in which the characters of an element of information are transferred in sequence over a single path in consecutive time positions.

service routine — Digital Computer Programming. A routine designed to assist in the actual operation of the computer. Tape comparison, block location, certain post mortems, and correction routines fall in this class.

servomechanism — A power-driven apparatus that exerts a strong force and supplements a primary control operated by a comparatively feeble force.

shift — To move the characters of a unit of information columnwise right or left. In the case of a number, this is equivalent to multiplying or dividing by a power of the base of notation (usually ten or two). This is regularly performed as a special rapid operation, much faster than usual multiplication or division.

sign digit — A one or a zero used to designate the algebraic sign of a quantity plus or minus.

significant digits — Computation. Digits appearing in the coefficient of a number when the number is written as a coefficient between 1.000.....and 9.999.....times a power of ten (called scientific normal form); and similarly for any base of notation other than 10. Examples: .000376, which is equal to 3.76 times 10^{-4}, has three significant digits; 12 million, equal to 1.2 times 10^7 has two significant digits; 300600, equal to 3.006 times 10^5, has four significant digits; in "J. B. Smith's book had exactly 1000 pages", the 1000 has four significant digits, although ordinarily 1000 would have only one significant digit.

simulation — The representation of physical systems by computers, models, and associated equipment.

single-address — Same as "one-address", which see.

skip (noun) — Digital Computer Programming. An instruction to proceed to the next instruction; a "blank" instruction.

slow memory — Computers. Sections of the memory from which information may be obtained automatically but not at the fastest rate of the several sections.

sonic delay line — A delay line which uses pulses of motion of the molecules of the medium (sound pulses) in contrast with an electrical delay line which uses electrical pulses in a wire or in an assembly of coils and capacitors.

sort — To arrange items of information according to rules depending upon a key or field contained by the items, such as previously chosen classes of items.

sorter — Punch Card Machines. A machine which sorts cards according to the punches in a specified column of the card.

specific coding — Digital Computer Programming. Coding in which all addresses refer to specific registers and locations.

specific routine — Digital Computer Programming. A routine expressed in specific computer coding designed to solve a particular mathematical, logical, or data-handling problem.

standardize — Computation. To adjust the exponent and coefficient of a floating-point result so that the coefficient lies in the prescribed normal range.

static storage — Computers. Storage such that information is fixed in space and available at any time provided the power is on; for example, flip-flop, electrostatic, or coincident-current magnetic-core storage.

static subroutine — Digital Computer Programming. A subroutine which involves no parameters other than the addresses of the operands. This is a subroutine which requires only the relative addresses of the operands, their insertion, and its transformation from relative to specific coding.

storage — Computers. 1. The unit which holds or retains items of information. 2. Any device into which information can be introduced, held, and then extracted at a later time. The mechanism or medium in which the information is stored need not form an integral part of a computer. Synonyms: memory, store (in English usage).

storage capacity — Same as "memory capacity", which see.

storage operation — One of the operations of reading, transferring, storing, or writing information.

storage register — A register in the memory or storage of the computer, in contrast with a register in one of the other units of the computer.

storage tube — Same as "electrostatic storage tube", which see.

store (noun) — Same as "storage", which see.

store (verb) — To transfer a piece of information to a device from which the information unaltered can be obtained at a later time.

subprogram — A part of a program.

subroutine — Computers. 1. A short or repeated sequence of instructions for a computer to solve a part of a problem; a part of a routine. 2. The sequence of instructions necessary to direct the computer to carry out a well-defined mathematical or logical operation; a subunit of a routine. A subroutine is often written in relative or symbolic coding even when the routine to which it belongs is not.

summary punch — Punch Card Machines. A punch card machine which may be attached by a many-wire cable to another machine (for example, a tabulator), and which will punch out on a card the information produced or calculated or summarized by the other machine.

summation check — Computer Operation. A redundant check in which groups of digits are summed, usually without regard for overflow, and that sum checked against a previously computed sum to verify accuracy of computation.

symbolic address — Digital Computer Programming. A label chosen to identify a particular word, function or other information in a routine, independent of the location of the information, within the routine. Also called "floating address".

symbolic logic — Exact reasoning about nonnumerical relations using symbols that are efficient in calculation. A branch of this subject known as Boolean algebra has been of considerable assistance in the logical design of computing circuits. Also called "mathematical logic".

synchronous computer — An automatic digital computer where the performance of all ordinary operations starts with equally spaced signals from a master clock.

T: tabulator — Punch Card Machines. A punch card machine which takes in punch cards and instructions and produces lists, totals, and tabulations of the information on separate forms or on continuous paper.

tag — Digital Computer Programming. A unit of information, whose composition differs from that of other members of the set so that it can be used as a marker or label; a sentinel.

tank — A unit of delay-line storage, usually of mercury and operating acoustically, containing a set of channels each forming a separate recirculation path.

tape — Computers. Magnetic tape or punched paper tape, sometimes other kinds of tape.

tape feed — A mechanism which will feed tape to be read or sensed by the machine.

temporary storage — Computers. Internal storage locations reserved for intermediate and partial results.

test routine — Digital Computer Programming. A routine designed to show that a computer is functioning properly.

three-address (adjective) — Digital Computer Programming. Having the property that each complete instruction includes an operation and specifies the location of three registers.

torque amplifier — Analog Computers. A device possessing input and output shafts and supplying work to rotate the output shaft in positional correspondence with the input shaft without imposing any significant torque on the input shaft.

track — Computers. In a magnetic drum or magnetic tape, a single path containing a set of pulses.

transcribe — To copy, with or without translating, from one external storage medium to another.

transfer (verb) — 1. To transfer data; to copy, exchange, read, record, store, transmit, transport, or write data. To transfer does not modify the information. 2. To transfer control of a computer.

transfer (noun) — An act of transferring.

transfer check — A check that an operation of transferring has been correctly carried out.

transfer instruction — Digital Computer Programming. An instruction or signal which conditionally or unconditionally specifies the location of the next instruction and directs the computer to that instruction. See "jump".

transform — Digital Computer Programming. To change information in structure or composition without significantly altering the meaning or value; to normalize, edit, or substitute.

translate — Computers. To change information from one language to another without significantly affecting the meaning.

trouble-location problem — A test problem whose incorrect solution supplies information on the location of faulty equipment; used after a check problem has shown that a fault exists.

trouble-shoot — To search for the cause for a coding mistake or a computer malfunction in order to remove it.

truncate — Computation. To drop digits of a number or terms of a series thus lessening precision. See "precision". For example, the number pi "3.14159265 ...." is "truncated" to three figures in "3.14".

truncation error — Computation. The error resulting from the use of only a finite number of terms of an infinite series, or from the approximation of operations in the infinitesimal calculus by operations in the calculus of finite differences.

trunk — A path over which information is transferred; a bus.

twin check — A continuous check of computer operations achieved by duplication of the hardware to perform them together with automatic comparison.

two-address (adjective)—Digital Computer Programming. Having the property that each complete instruction includes an operation and specifies the location of two registers, usually one containing an operand and the other containing the result of the operation.

U: unconditional transfer — Digital Computer Programming. In a digital computer which ordinarily obtains its instructions serially from an ordered sequence, an instruction which causes the following instruction to be taken from an address which is not the next one in the sequence.

unwind — Digital Computer Programming. To code explicitly, at length and in full, all the operations of a cycle, in such a way as to eliminate all red-tape operations. Unwinding may be performed automatically by the computer during assembly, generation, or compilation.

unpack — Digital Computer Programming. To separate packed items of information each into a separate machine word. See "pack".

V: validity — Computation. Correctness, especially the degree of closeness by which an iterated approximation approaches the desired correct result.

variable cycle operation — Computer Operation. Operation of a computer whereby any cycle of operation may be longer or shorter than the average. This is the kind of operation in an "asynchronous computer".

verifier — 1. Punch Card Machines. A punch card machine operated manually which reports by signals whether punched holes have been inserted in the wrong places in a punch card or have not been inserted at all. 2. Computers. An auxiliary device on which a previous manual transcription of data can be verified by comparing a current manual transcription of it character-by-character during the current process.

verify — 1. To check, usually with an automatic machine, one typing or recording of data against another in order to minimize the number of human errors in the data transcription. 2. In preparing information for a computer, to make certain that the information as prepared is correct.

volatile memory — Computers. Memory or storage having the property that if the power is turned off, the information vanishes; delay line memory, electrostatic storage tubes.

volatile storage — Same as "volatile memory".

W: Williams tube — Digital Computers. A cathode-ray tube for electrostatic storage of information of the type designed by F. C. Williams of the University of Manchester, England.

word — Digital Computers. An ordered set of characters which has at least one meaning and is stored and transferred by the computer circuits as a unit. Also called "machine word" or "information word", which may however be different since the machine word may include spaces between words while the information word may not. Ordinarily, a word has a fixed number of characters, and is treated by the control unit as an instruction, and by the arithmetic unit as a quantity. For example, a computer may regularly handle numbers or instructions in units of 36 binary digits.

word-time — Digital Computers. Especially in reference to words stored serially, the time required to transfer a machine word from one storage device to another.

working storage — Digital Computers. A portion of the internal storage reserved for data upon which operations are currently being performed, and for intermediate and partial results, like a work-sheet in pencil and paper calculation.

write — Digital Computers. 1. To copy information usually from internal to external storage. 2. To transfer information to an output medium. 3. To record information in a register, location, or other storage device or medium.

Z: zero — Digital Computers. The computer's conceptions of zero. Note: The computer may provide for two zeros. Positive binary zero is represented by the absence of digits or pulses in a word. Negative binary zero in a computer operating with ones' complements may be represented by a pulse in every pulse position in a word. In a coded decimal computer, decimal zero and binary zero may not have the same representation. In most computers, there exist distinct and valid representations both for positive and for negative zero.

zero-address instruction — Digital Computers. An instruction specifying an operation in which the location of the operands are defined by the computer code, so that no address need be given explicitly.

zero-access storage — Digital Computers. Storage for which the latency or waiting time is always negligible.

zero-suppression — The elimination of non-significant zeros to the left of the integral part of a quantity before printing is begun. To suppress these zeros is one of the operations in editing.

zone — 1. Punch Cards. Any of the three top positions 12, 11, and 0. In these zone positions a second punch can be inserted, so that with punches in the remaining positions 1 to 9, enough two-punch combinations are obtained to represent alphabetic characters.
2. Digital Computers. A portion of internal storage allocated for a particular purpose.

VIII:5 INDEX

NOTES: This index does not include terms and expressions occurring in Section VIII, Miscellaneous.

A phrase is ordinarily entered in its alphabetical place according to the first word in the phrase: for example, "binary arithmetic" is under b *for "binary,"* *not* a *for "arithmetic."*

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